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Evaluation of the National Throughput Benefits of the Civil Tilt Rotor

Jesse Johnson, Virginia Stouffer, Dou Long, Joana Gribko
Logistics Management Institute, McLean, Virginia

September 2001

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Chapter 1
Introduction and Summary

The air transportation system is a key part of the U.S. and global economic infrastructure. In recent years, this system, by any measure of usage—operations, enplanements, or revenue passenger miles (RPMs)—has grown rapidly. The rapid growth in demand has not been matched; however, by commensurate increases in the ability of airports and the airspace system to handle the additional traffic. As a result, the air transportation system is approaching capacity and airlines will face excessive delays or significant constraints on service unless capacity is expanded. To expand capacity, the air traffic management system must be improved.

To improve the air traffic management system, the National Aeronautics and Space Administration (NASA) Aerospace Technology Enterprise developed the strategic goal of tripling air traffic throughput over the next 10 years, in all weather conditions, while at least maintaining current safety standards. As the first step in meeting that goal, the NASA Intercenter Systems Analysis Team (ISAT) is evaluating the contribution of existing programs to meet that goal. A major part of the study is an examination of the ability of the National Airspace System (NAS) to meet the predicted growth in travel demand and the potential benefits of technology infusion to expand NAS capacity. We previously analyzed the effects of the addition of two technology elements—Terminal Area Productivity (TAP) and Advanced Air Transportation Technologies (AATT).[1]

The next program we must analyze is not specific to airspace or aircraft technology. The program incorporates a fundamentally different vehicle to improve throughput: the civil tilt rotor (CTR). The CTR has the unique operating characteristic of being able to take off and land like a rotorcraft (vertical take off and landing, or VTOL, capability) but cruises like a traditional fixed-wing aircraft. The CTR also can operate in a short take off and landing (STOL) mode; generally, with a greater payload capacity (i.e., more passengers) than when operating in the VTOL mode. CTR could expand access to major airports without interfering with fixed-wing aircraft operating on congested runways and it could add service to new markets without the infrastructure support needed for fixed-wing aircraft.

During FY 1999, we preliminarily assessed the feasibility of operating CTRs at two major U.S. airports as part of the annual review of NASA aerospace goals by

[1] *Modeling Air Traffic Management Technologies with a Queuing Network model of the National Airspace System*, David Lee, Dou Long, et al, NASA/CR-1999-208988, January 1999.

the ISAT.[2] This current study expands the analysis and concepts of that study to the complete NAS to quantify the national throughput effects of the CTR.

STUDY OVERVIEW

We conducted this study in two major parts. The first part was a macroscopic and systems study focusing on operations and delay effects resulting from adding the CTR into the NAS. The years chosen for analysis were 1997, 2007, and 2022. The year 1997 is the NASA baseline year for beginning the analysis of increasing throughput. The year 2007 represents the near future, when the first set of technologies is implemented to offset the first predicted debilitative effects of delay. The year 2022 represents the far future, when the projected growth has occurred and NASA's strategies have had the chance to be fully developed and implemented.

The second part of the study examined the effects of implementing CTRs at 63 specific airports, focusing on airport, airspace, and airport surface analysis. For this part of the study, we examined airport-specific limitations of CTR use, including the number, sizes, lengths, and layouts of runways, as well as airspace configuration issues. The study provides the initial blueprint for specific changes—involving construction and operational factors—required to implement the CTR at a specific airport.

CONCLUSIONS

Analysis of Operations and Delays

The CTR's unique design is simultaneously its best and worst feature. The currently examined scenario does not the use of the CTR's vertical lift capability, instead assumes STOL operations only. Therefore, the assumed operating mode for this study requires runways—although not jet runways. Assuming both the CTR and the associated runways are built, the results are real, albeit somewhat localized by specific characterization of the specific airport.

Operating in the STOL mode, the CTR can remove approximately 10 percent of the operations nationally, this effect ranges between 0 and 100 percent of the operations at any particular airport. Removing these operations drops the average delay down to levels consistent with 2007 unconstrained baseline traffic levels. RPMs decline, but because of the short haul nature and low passenger capacity of the CTR flights, the drop in delays is only about 3 percent. The key issue is how those newly available operations slots will be used. By reusing those operations, enplanements and RPMs will increase, but at a disproportionate increase in average time of delay. The results of the operations analysis are shown in Table 1-1.

[2] *Civil Tiltrotor Feasibility Study for the New York and Washington Terminal Areas*, Virginia Stouffer, Jesse Johnson, and Joana Gribko, LMI Contractor Report NS904S2, February 2000.

Analysis of VTOL operation was beyond the scope of this study. If the CTR can operate VTOL with acceptable economics and air traffic management, it could lead to even larger increases in capacity.

Table 1-1. Operations Analysis Results

		1997	2007	2017	2022
	Baseline case				
1	Total operations	20,932,000	25,779,000	31,173,000	33,106,000
2	OAG operations	16,991,000	21,572,000	26,689,000	28,515,000
3	LMINET CTR operations Removed		2,555,883	2,863,836	2,996,028
4	Delay per total operation (minutes)	6.7	21.3	86.6	122.9
	CTR implemented with no operations replacement				
5	Minimum total operations (1-3)		23,223,117	28,309,164	30,109,972
6	Minimum OAG operations (2-3)		19,016,117	23,825,164	25,518,972
7	Percentage total operations removed (3÷1)		9.9	9.2	9.1
8	Percentage OAG operations removed (3÷2)		11.9	10.7	10.5
9	Delay per total operation (minutes)		9.1	18.3	22.8
	CTR implemented with maximum operations replacement (1+3)				
10	Maximum total operations (2+3)		28,334,883	34,036,836	36,102,028
11	Maximum OAG operations (3÷1)		24,127,883	29,552,836	31,511,028
12	Percentage total operations added(3÷2)		9.9	9.2	9.1
13	Percentage OAG operations added		11.9	10.7	10.5
14	Delay per total operation (minutes)		21.3	86.6	122.9

Table 1-2 shows the RPM analysis. Removing the turbo jets/props has a real effect on the RPMs. The CTR replaceable flights are short-haul, low-passenger flights. If replaced by jet aircraft, on average, these aircraft will be medium-haul jet aircraft. Adding operations will increase RPMs, but the effect, as a percent of the baseline, declines over time. The increase in RPMs ranges from a high of 8.7 percent in 2007 to a low 4.6 percent in 2022. This declining rate of additional RPM growth is caused by the combination of limited CTR dedicated runway capacity at some airports (which forces the CTRs onto the jet runways) as well as the general trend of longer haul flights increasing at a faster rate than shorter haul flights. However, the main point is that both operations and RPMs can be increased, but the price of those is an increasing delay time.

Table 1-2. RPM Analysis Results

		2007	2017	2022
1	Baseline Total RPMs (billions)	932.8	1,495.4	1,867.7
2	CTR Replaceable RPMs (billions)	14.8	21.5	26.3
3	Maximum Operations replaced RPMs (billions)	95.8	107.4	112.4
4	RPM Replacement Rates (3÷1)	6.5	5.0	4.3
5	CTR Implemented RPMs/No operations replacement (billions) (1-2)	918.0	1,473.9	1,841.4
6	Percentage RPMs Decrease/with CTR (billions) (2÷1)	1.6	1.4	1.4
7	Maximum RPMs/with CTR (billions) (1-2+3)	1,013.8	1,581.3	1,953.8
8	Percentage RPMs Increase/with CTR (billions) (3-2) = 1	8.7	5.7	4.6

These national effects are not descriptive of individual airports. The CTR in vertical flight mode could be used at almost any airport. The STOL mode can only be used at airports with appropriate runway space. Using the STOL mode at these airports provides additional capacity that can enable a more effective tradeoff between reducing delays and increasing operations. Not all airports have the space for a CTR-dedicated runway. Not all airports will have the sufficient turbojet/prop mix to justify the investment in the needed infrastructure.

Twenty-three airports have no space for operating the CTR in the STOL mode. These airports are ATL, BOS, DCA, JFK, LAX, MDW, SEA, BNA, BUR, DAL, FLL, GSO, ISP, LAS, MEM, MIA, OAK, PBI, PDX, RNO, SNA, STL, and TPA.[3] Any CTR operations at these airports will have to be strictly in the vertical mode. Forty major airports have the space for at least one CTR-only runway or two shared runways. At these airports, the issues are, “Is there enough demand to justify the investment?” or, “Can demand be increased or shifted to those airports to justify the investment?”

The value and extra costs of VTOL operations requires tradeoffs that were beyond the scope of the current analysis, but this is a very germane issue for future study.

The 40 airports can be easily divided into those with CTR runway capacity above and below 75 percent based on 2022 traffic patterns (equal to 97,000 operations). The 14 airports below that threshold are BDL, LGA, MSY, DAY, HOU, AUS, SAT, MCI, ABQ, ELP, ONT, SMF, SJC, and LGB. The remaining 26 airports exceed that threshold. They are HPN, EWR, PHL, BWI, IAD, RDU, CLT, MCO, SDF, CVG, CMH, IND, CLE, DTW, PIT, SYR, MKE, ORD, IAH, DFW, MSP, DEN, PHX, SLC, SAN, and SFO.[4]

[3] Airport Identifier codes are in Appendix A.

[4] TEP currently has no commercial operations, for this study we assumed that that practice would continue.

CTR Economics

The CTR is only a notional design, which limits some of the analysis. The sole source of CTR manufacturing projections is the 1995 CTRDAC study.[5] We have used the specified vehicle design, operating parameters, manufacturing costs, and selling prices in this study. We adjusted dollar values to year 2000 dollars.

We developed a standard cost-quantity curve using the given data. The assumption is that breakeven is 506 aircraft, and a total demand is approximately 2,000 aircraft. We now know that any significant sales of CTRs are likely to be accompanied or preceded by reconfiguring airports to accept them. The reconfiguration will include opening or reallocating stub runways, as well as constructing new CTR-dedicated runways and the associated infrastructure.

The operating costs of the fixed-wing aircraft that the CTRs are expected to replace are known. They represent, at best, a target for the CTR to meet. Powered-lift and short-runway take offs and landings are expensive capabilities to design and manufacture, regardless of whether or not they are actually used. Our analysis of the fleet inventory shows that large numbers of the short-haul aircraft are relatively old, and the introduction of the CTR may be an impetus to switch vehicle types. But our analysis also shows that some air carriers have begun to switch already, and they have shifted to a new generation of regional jets with better operating costs and the ability to carry 50 passengers between 200 and 1,200 miles.

Ultimately, the demand for CTRs will determine its success or failure. This study shows that not all the turboprop and jet operations can be removed from the jet runways without building large numbers of CTR-dedicated runways[6] and incorporating vertical operations. New and novel uses for the CTR must be found and implemented for this project to come to fruition. Manufacturers, carriers, airport authorities, and entrepreneurs need to examine new options and implementation schemes. The options and schemes include local and regional airport shuttle systems, services to existing or projected heliports and vertiports, and added air service to smaller markets without major runway construction.

In addition, the geography of Europe, South America, and Asia may define a sizeable CTR market. The European market is relatively compact. CTRs could provide some of the same air services that currently are provided by fixed-wing aircraft. The vastness and lack of development in South America and Asia (especially China) define another market for the CTR. In this case, the CTR enables a transport mode with less infrastructure investment than airports, roads, or rail.

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[5] Civil Tiltrotor Development Advisory Committee, *Report to Congress, Final Report*, volumes 1 and 2, December 1995.

[6] CTR-dedicated runways will be much shorter than conventional jet runways, as well as less expensive to build.

Capacity Analysis

Eighty-nine percent of the airports we surveyed (56 of 63) have open existing concrete surfaces or open land and a capacity for either independent or staggered operations on a new CTR runway. Nearly half of the airports (30 of 63) were rated for an independent new CTR runway (which may or may not be shared with turboprops in the near term). These figures indicate that, in general, the busiest airports in the United States have room for additional operations if CTRs are added to U.S. fleets. These additional operations create additional capacity. New dependent operations could add 12 operations each hour to an airport; independent operations can easily add 30 operations each hour, if demand exists for those flights.

Converting an existing concrete surface, such as a taxiway or parking area, to a CTR runway is estimated to cost $100,000 to $15 million; the average is approximately $7–$8 million in year 2000 dollars. Carving a new runway from available land (ignoring the cost of land acquisition) can cost $500,000 to $51 million; the average is $7–$19 million, depending on the distance from the main terminal. Purchasing land that is currently used for residential, industrial parks, and other purposes usually doubles the cost of construction.

On the other hand, seven airports received ratings indicating that CTRs would not add capacity. Because of a lack of available land or airspace, new CTR STOL operations would be forced to share the main runways at these airports:

- San Jose
- Fort Lauderdale
- Islip
- Las Vegas McCarran International
- Memphis International
- Santa Ana
- Tampa International.

Given the surprising number of airports with enough land available for CTR operations and the potential for new independent operations, the effect of implementing CTR nationally could be a sizable increase in capacity.

Chapter 2
Operations and Delay Analysis

The CTR is a means for adding additional throughput and capacity to the NAS, in a different way than other efforts to date. LMI has helped NASA analyze ways to increase throughput and capacity—primarily by adding new technology to fixed-wing aircraft or by changing and adding to the air traffic management (ATM) system—primarily for improving the flow of fixed-wing aircraft traffic. The CTR represents the next step in examining the total solution for increasing capacity.

We will use three metrics for measuring throughput and capacity: operations, RPMs, and delay. Operations refers to a takeoff or landing; this metric measures vehicle frequency. RPMs constitute a multiple measure of passenger frequency and distances flown and profit. Delay per flight represents the degradation of operations or vehicle frequency statistics, as well as the passenger frequency statistic portion of RPMs.

In this chapter, we examine the macro-level effects of implementing the CTR. The principal tool used for this analysis is LMINET[1]—a queuing network model of the NAS. LMINET is implemented for 64 airports[2], which account for more that 84 percent of air carrier operations, as reported in the Department of Transportation (DOT) Forms T-100. In general terms, LMINET models flights among a set of airports by linking queuing network models of airports with sequences of queuing models of Terminal Radar Approach Control (TRACON) and Air Route Traffic Control Center (ARTCC) sectors.

First, we examine a baseline case, analyzing the three metrics for the years 1997, 2007, and 2022. Then we remove the flights that could be replaced by CTRs from the input data and perform the simulation again. The results are the metrics when the CTR is implemented and portions of the turboprop and turbojet flights replaced by using CTR flights are removed from the traffic flow.

The primary assumption in this macro study is that the CTR can operate in the terminal area without affecting the flow of fixed-wing traffic. Therefore, adding CTR flights decreases delay time.

[1] *Modeling Air Traffic Management Technologies with a Queuing Network Model of the National Airspace System*, David Lee, Dou Long, et al, NASA/CR-1999-208988, January 1999.

[2] The 64 airports are referenced by 3-letter airport identifier codes. The codes are defined in Appendix A.

OFFICIAL AIRLINE GUIDE ANALYSIS

We began this study by examining the *Official Airline Guide* (OAG). The OAG is a monthly database of every scheduled flight in the world. This database is a huge file, with an average size of 165,000 lines per month, each line representing a scheduled flight for that month. Using the October 1999 OAG, we found the arrivals at each of the 64 LMINET airports. Although Teterboro is one of the 64 airports in the LMINET model, it has no commercial operations, so we excluded it from further analysis.

We then separated the arrivals into three categories:

- Jet aircraft of 51 seats or more and all cargo aircraft
- Turbojet and turboprop aircraft with flight segments of more than 500 miles
- Turbojet and turboprop aircraft with flight segments of 500 miles or less.

Table 2-1 lists the arrival data by category and airport. We define CTR-replaceable flights as flights that are flown on turbojets and turboprops with flight segments of less than 500 miles. All other flights—including jet flights of less than 500 miles that involve positioning, backhaul, or even high-passenger-capacity short-haul flights, as well as long-haul turbojet flights and medium-haul turboprop flights—are defined as nonreplaceable. Table 2-2 lists replaceable and nonreplaceable arrivals by airport.

Table 2-1. October 1999 Arrivals, by Distance and Aircraft Type

Airport	Total arrivals	Jets	Turbo jets/props > 500 miles	Turbo jets/props <= 500 miles
Totals	707,650	507,569	22,008	177,890
Percentage		0.72	0.03	0.25
ABQ	4,373	3,282	22	1,069
ATL	37,029	29,416	546	7,067
AUS	4,198	4,104	31	63
BDL	4,504	3,093	145	1,266
BNA	5,776	4,859	206	694
BOS	19,888	11,640	304	7,944
BUR	2,418	2,418	0	0
BWI	10,589	7,462	123	3,004
CLE	12,057	5,205	872	5,984
CLT	15,661	10,552	176	4,933
CMH	5,027	3,252	0	1,775
CVG	18,408	7,768	2176	8,464
DAL	4,574	4,232	0	342

Table 2-1. October 1999 Arrivals,
by Distance and Aircraft Type (Continued)

Airport	Total arrivals	Jets	Turbo jets/props > 500 miles	Turbo jets/props <= 500 miles
DAY	3,934	2,549	204	1,181
DCA	10,789	7,694	97	2,998
DEN	19,475	14,898	372	4,205
DFW	31,737	23,989	420	9,950
DTW	34,359	15,342	0	4,375
ELP	2,494	2,254	44	196
EWR	18,048	13,751	795	3,502
FLL	6,826	4,732	29	2,065
GSO	2,459	1,602	0	857
HOU	5,832	5,136	124	572
HPN	2,133	538	93	1,502
IAD	18,218	5,205	872	5980
IAH	17,983	13,133	798	4,052
IND	5,389	3,500	25	1,864
ISP	1,774	766	186	822
JFK	15,738	9,270	0	6,468
LAS	13,088	12,496	31	561
LAX	31,908	22,826	0	9,082
LGA	15,222	11,257	321	3,644
LGB	357	357	0	0
MCI	8,599	6,535	367	1,697
MCO	12,721	9,789	167	2,765
MDW	7,799	6,656	0	1,143
MEM	9,352	6,123	210	3,019
MIA	16,501	12,308	0	4,193
MKE	6,298	3,485	163	2,456
MSP	19,063	14,795	349	3,919
MSY	5,244	4,620	180	444
OAK	5,043	4,981	31	31
ONT	3,597	3,209	0	388
ORD	37,734	30,804	912	6,018
PBI	2,917	2,021	62	834
PDX	9,768	5,968	31	3,769
PHL	17,422	11,396	359	5,676
PHX	18,727	15,921	570	2,236
PIT	17,266	9,090	190	7,986
RDU	8,595	4,506	492	3,597
RNO	3,341	3,126	0	215
SAN	8,542	6,218	0	2,234
SAT	3,721	3,466	31	224
SDF	3,133	2,487	87	559

Table 2-1. October 1999 Arrivals, by Distance and Aircraft Type (Continued)

Airport	Total arrivals	Jets	Turbo jets/props > 500 miles	Turbo jets/props <= 500 miles
SEA	17,897	11523	0	6,344
SFO	17,813	14,480	62	3,271
SJC	5,981	5,870	0	111
SLC	10,531	7,205	367	2,959
SMF	4,142	3,450	0	692
SNA	4,181	3,788	31	362
STL	19,733	15,621	338	3,774
SYR	3,166	1,063	31	2,072
TPA	8,608	5,929	10	2,669

Table 2-2. CTR-Replaceable Flights, by Airport

Airport	Total arrivals	Non-replaceable	Replaceable	Non-replaceable	Replaceable
Totals	707,650	530,624	176,843		
Fraction				0.75	0.25
ABQ	4,373	3,304	1,069	0.76	0.24
ATL	37,029	29,962	7,067	0.81	0.19
AUS	4,198	4,135	63	0.99	0.02
BDL	4,504	3,238	1,266	0.72	0.28
BNA	5,776	5,065	694	0.88	0.12
BOS	19,888	11,944	7,944	0.60	0.40
BUR	2,418	2,418	0	1.00	0.00
BWI	10,589	7,585	3,004	0.72	0.28
CLE	12,057	6,077	5,984	0.50	0.50
CLT	15,661	10,728	4,933	0.69	0.31
CMH	5,027	3,252	1,775	0.65	0.35
CVG	18,408	9,944	8,464	0.54	0.46
DAL	4,574	4,232	342	0.93	0.07
DAY	3,934	2,753	1,181	0.70	0.30
DCA	10,789	7,791	2,998	0.72	0.28
DEN	19,475	15,270	4,205	0.78	0.22
DFW	34,359	24,409	9,950	0.71	0.29
DTW	19,717	15,342	4,375	0.78	0.22
ELP	2,494	2,298	196	0.92	0.08
EWR	18,048	14,546	3,502	0.81	0.19
FLL	6,826	4,761	2,065	0.70	0.30
GSO	2,459	1,602	857	0.65	0.35
HOU	5,832	5,260	572	0.90	0.10

Table 2-2. CTR-Replaceable Flights, by Airport (Continued)

Airport	Total arrivals	Non-replaceable	Replaceable	Non-replaceable	Replaceable
HPN	2,133	631	1,502	0.30	0.70
IAD	18,218	8706	9512	0.48	0.52
IAH	17,983	13,931	4,052	0.77	0.23
IND	5,389	3,525	1,864	0.65	0.35
ISP	1,774	952	822	0.54	0.46
JFK	15,738	9,270	6,468	0.59	0.41
LAS	13,088	12,527	561	0.96	0.04
LAX	31,908	22,826	9,082	0.72	0.28
LGA	15,222	11,578	3,644	0.76	0.24
LGB	357	357	0	1.00	0.00
MCI	8,599	6,902	1,697	0.80	0.20
MCO	12,721	9,956	2,765	0.78	0.22
MDW	7,799	6,656	1,143	0.85	0.15
MEM	9,352	6,333	3,019	0.68	0.32
MIA	16,501	12,308	4,193	0.75	0.25
MKE	6,298	3,648	2,456	0.58	0.39
MSP	19,063	15,144	3,919	0.79	0.21
MSY	5,244	4,800	444	0.92	0.08
OAK	5,043	5,012	31	0.99	0.01
ONT	3,597	3,209	388	0.89	0.11
ORD	37,734	31,716	6,018	0.84	0.16
PBI	2,917	2,083	834	0.71	0.29
PDX	9,768	5,999	3,769	0.61	0.39
PHL	17,422	11,755	5,676	0.67	0.33
PHX	18,727	16,491	2,236	0.88	0.12
PIT	17,266	9,280	7,986	0.54	0.46
RDU	8,595	4,998	3,597	0.58	0.42
RNO	3,341	3,126	215	0.94	0.06
SAN	8,542	6,218	2,234	0.73	0.27
SAT	3,721	3,497	224	0.94	0.06
SDF	3,133	2,574	559	0.82	0.18
SEA	17,897	11,523	6,344	0.64	0.36
SFO	17,813	14,542	3,271	0.82	0.18
SJC	5,981	5,870	111	0.98	0.02
SLC	10,531	7,572	2,959	0.72	0.28
SMF	4,142	3,450	692	0.83	0.16
SNA	4,181	3,819	362	0.91	0.09
STL	19,733	15,959	3,774	0.81	0.19
SYR	3,166	1,094	2,072	0.35	0.65
TPA	8,608	5,939	2,669	0.69	0.31

If the CTR could be implemented and replace all of the appropriate flights, the effects would depend on the method of implementation. For example, if the goal were to lower the average national delay or to minimize the variance in the average national delay, CTRs would be implemented first at airports with the most replaceable operations. Table 2-3 lists the top 10 airports in terms of number of operations. These airports, with the exception of LAX and BOS, are major hub airports. LAX is the main gateway airport on the West Coast, and BOS is the northern endpoint of the high-density Northeast corridor.

Table 2-3. Top Ten Airports, Monthly Arrivals

Airport	Total arrivals	Nonreplaceable	Replaceable	Percent replaceable
ORD	37,734	31,716	6,018	15.9
ATL	37,029	29,962	7,067	19.1
DFW	34,359	24,409	9,950	29.0
LAX	31,908	22,826	9,082	28.5
BOS	19,888	11,944	7,944	39.9
STL	19,733	15,959	3,774	19.1
DTW	19,717	15,342	4,375	22.2
DEN	19,475	15,270	4,205	21.6
MSP	19,063	15,144	3,919	20.6
PHX	18,727	16,491	2,236	11.9

If the goal were to maximize the improvement in delay at each airport, the CTR implementation scheme would be based on the highest percentage of CTR-replaceable operations at an airport. Table 2-4 lists the ten airports with the highest percentage of operations that can be replaced with the CTR. Half of these have a relatively small number of operations. BOS is included because it is the northern edge of the busy Northeast corridor. BOS also is in the top 10 in terms of operations. The JFK operations represent a large number of the high-density East Coast traffic funneled to them for international flights. The remaining three large airports, CLE, CVG, and PIT, function as national or regional hubs. Short-haul flights are used to assemble demand at these airports.

Table 2-4. Top Ten Airports, Percentage of CTR-Replaceable Operations

Airport	Total arrivals	Nonreplaceable	Replaceable	Percent replaceable
HPN	2,133	631	1,502	70.4
SYR	3,166	1,094	2,072	65.5
IAD	18,218	8,706	9,512	52.2
CLE	12,057	6,077	5,984	49.6
ISP	1,774	952	822	46.3
PIT	17,266	9,280	7,986	46.3
CVG	18,408	9,944	8,464	46.0
MKE	6,298	3,648	2,650	42.1
RDU	8,595	4,998	3,597	41.9
JFK	15,738	9,270	6,468	41.1

The last look is at the 10 airports with the most CTR-replaceable operations. This distinction is important because this case represents the best opportunity to reduce delay times and increase throughput locally. But, if these airports also are national hubs, implementing CTRs at these airports can generate a ripple effect throughout the rest of the NAS.

Table 2-5. Top Ten Airports, Number of CTR-Replaceable Operations

Airport	Total arrivals	Nonreplaceable	Replaceable	Percent replaceable
DFW	34,359	24,409	9,950	29.0
IAD	18,218	8,706	9,512	52.2
LAX	31,908	22,826	9,082	28.5
CVG	18,408	9,944	8,464	46.0
PIT	17,266	9,280	7,986	46.3
BOS	19,888	11,944	7,944	39.9
ATL	37,029	29,962	7,067	19.1
JFK	15,738	9,270	6,468	41.1
SEA	17,867	11,523	6,344	35.5
ORD	37,734	31,716	6,018	15.9

This hub analysis is important because most hubs are associated with specific carriers, and each carrier has a different strategy for its operations (e.g., national operations or strong operations in a specific region of the country). The characteristics of the specific hub—including size, geographical location, number and shares of competing airlines, and number and percentage of “pass-through” customers—dictate the type of aircraft used at that airport. Thus, the hub strategy of replacing fixed-wing operations with CTR operations reflects a strategic corporate decision about how the CTR fits into the specific carrier’s operations.

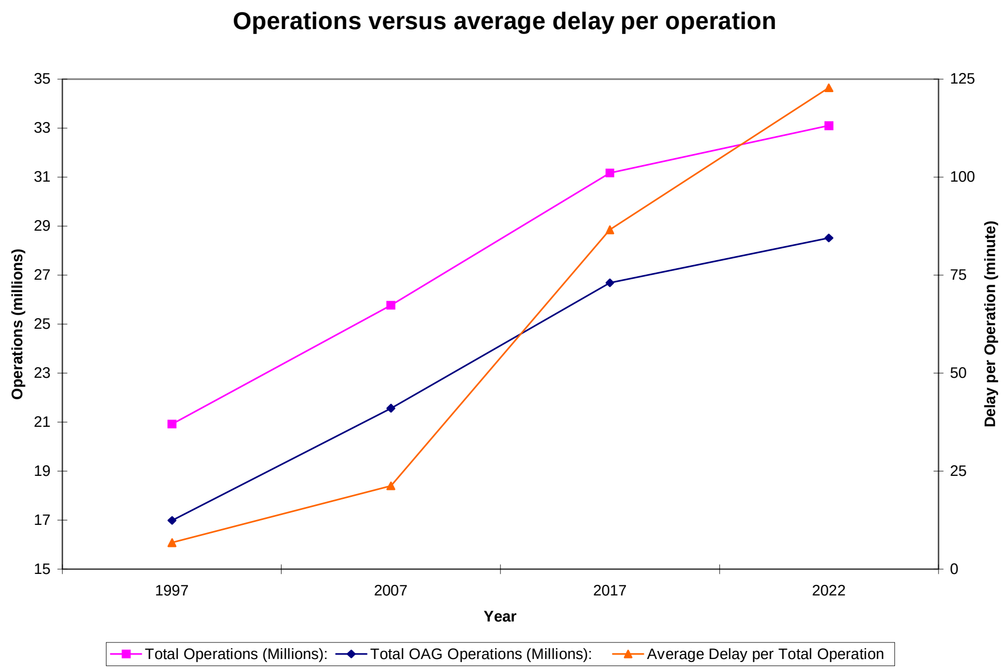
Baseline Delay Analysis

We used LMINET to produce a set of baseline delays for the target years of 1997, 2007, 2017, and 2022. The specific case we used is known as unconstrained demand. In that case, the Federal Aviation Administration (FAA)-predicted growth occurs as planned, but the resultant delay and congestion from limited air traffic capacities are not assumed to be limits on air traffic growth. Table 2-5 shows the total system-level results. OAG operations represent scheduled passenger and cargo traffic. Total operations include OAG operations as well as operations performed by charter, regional, commuter, air taxi, and unscheduled carriers. Total RPMs are those resulting from total operations. Although operations and RPMs are both increasing, average delay—therefore total delay minutes—is increasing much faster. From 1997 to 2022, operations and RPMs increase almost 70 percent. Average delay per operation increases 1,700 percent, and total delay minutes increase an astounding 2,800 percent. These data are listed in Table 2-6 and depicted graphically in Figure 2-1.

Table 2-6. Summary of Baseline LMINET Results

	1997	2007	2017	2022
Total operations (millions)	20.93	25.78	31.17	33.11
Total OAG operations (millions)	16.99	21.57	26.69	28.52
Total RPMs (billions)	N/A	932.8	1495.4	1867.7
Average delay per total operation (minutes)	6.71	21.25	86.55	122.85
Total delay minutes (millions)	140.5	547.8	2,698.0	4,067.1

Figure 2-1. Summary of LMINET Simulation



The growth in average delay per operation is critical. It shows that a thoroughly congested air transportation system will occur in the near future. In reality, the delays would never get that high; operations and resulting RPMs would be scaled back until the delay was at "acceptable" levels.

Table 2-7 shows the resultant annual operations and 25-year growth rates for each of the 64 LMINET airports. The magnitudes of the numbers represent the results of a 3-day simulation run under three different weather scenarios. The three weather days can be best characterized as

- a good-weather, summer day;
- a degraded-weather spring day; and
- a bad-weather winter day.

The differing growth rates are evidence of an increasing, but uneven, air traffic demand. The national average is an increase of 68 percent. Operations at three airports (MCO, IAH, and LAS) are expected to double; 44 of the 64 airports have growth rates that are less than the national average. This baseline case, along with the OAG analysis, lays the framework for simulating the substitution of the CTR.

Table 2-7. Simulation Results—Baseline Operations by Airport

Airport	1997	2007	2017	2022	Percentage increase 1997–2022
BOS	493,562	547,406	595,907	617,823	25.2
BDL	155,381	192,729	227,210	239,695	54.3
HPN	163,132	188,195	206,606	213,155	30.7
ISP	110,254	122,719	132,075	135,667	23.0
TEB	184,989	224,112	260,981	274,912	48.6
LGA	353,386	369,512	389,809	398,706	12.8
JFK	361,856	396,290	433,667	450,417	24.5
EWR	467,342	545,970	631,559	664,909	42.3
PHL	453,963	581,655	717,914	768,408	69.3
BWI	257,966	329,039	404,983	431,567	67.3
DCA	309,828	318,700	336,336	344,637	11.2
IAD	337,184	435,847	507,378	533,477	58.2
GSO	115,971	158,290	179,433	185,810	60.2
RDU	229,852	267,215	292,246	302,603	31.7
CLT	459,543	509,112	569,377	593,748	29.2
ATL	772,321	1,060,529	1,301,975	1,382,946	79.1
MCO	351,275	516,845	673,786	720,743	105.2
PBI	177,781	207,453	229,905	238,168	34.0
FLL	243,882	292,031	341,071	358,604	47.0
MIA	525,297	660,286	843,327	911,887	73.6
TPA	246,378	288,899	354,399	378,880	53.8
MSY	160,004	205,278	244,060	257,782	61.1
MEM	361,312	471,312	573,168	60,575	68.7
BNA	206,256	220,491	231,036	235,254	14.1
SDF	174,739	240,917	293,872	309,746	77.3
CVG	410,882	583,958	755,164	810,929	97.4
DAY	139,560	162,869	185,035	193,948	39.0
CMH	194,065	269,229	315,792	328,522	69.3
IND	230,332	316,005	393,735	418,263	81.6
CLE	310,754	420,327	511,454	544,800	75.3
DTW	541,072	643,490	829,655	900,526	66.4

Table 2-7. Simulation Results—Baseline Operations by Airport (Continued)

Airport	1997	2007	2017	2022	Percentage increase 1997–2022
PIT	450,461	523,466	584,356	608,271	35.0
SYR	124,573	154,576	169,404	173,685	39.4
MKE	197,653	274,650	319,500	331,930	67.9
ORD	888,521	1,000,170	1,161,079	1,226,794	38.1
MDW	260,057	320,498	382,008	402,339	54.7
STL	510,829	567,150	695,294	749,042	46.6
IAH	409,533	616,850	802,440	857,072	109.3
HOU	258,575	287,383	316,745	329,102	27.3
AUS	195,842	214,305	252,196	268,597	37.1
SAT	238,157	297,066	354,553	374,201	57.1
DAL	226,657	253,743	276,577	286,868	26.6
DFW	925,743	1,182,223	1,468,606	1,569,283	69.5
MSP	483,872	618,879	777,902	834,369	72.4
MCI	208,782	264,557	309,610	325,427	55.9
DEN	478,395	558,043	642,428	676,051	41.3
ABQ	177,984	232,918	276,739	291,043	63.5
ELP	113,937	140,642	162,542	169,071	48.4
PHX	525,079	642,972	860,011	938,203	78.7
SLC	369,615	470,255	601,508	643,786	74.2
LAS	442,453	608,305	822,198	891,069	101.4
SAN	217,745	273,236	349,459	378,052	73.6
SNA	373,423	408,703	498,864	533,940	43.0
LGB	251,772	241,035	246,903	248,984	–1.1
LAX	764,154	960,128	1,264,261	1,382,292	80.9
BUR	175,009	191,897	233,395	250,320	43.0
ONT	154,980	198,506	273,271	299,840	93.5
RNO	151,191	215,346	264,853	279,242	84.7
SMF	144,080	205,702	245,605	256,712	78.2
OAK	382,547	466,820	555,702	589,594	54.1
SFO	428,684	529,065	676,440	733,125	71.0
SJC	225,050	258,578	327,543	350,320	55.7
PDX	296,101	366,790	447,572	474,297	60.2
SEA	380,778	487,759	590,688	626,951	64.7

CTR Substitution

Table 2-2 shows the CTR-replaceable operations by airport, both numerically and by percentage. Table 2-6 shows the future operations by airport. The simple CTR substitution method would be to reduce the operations at each airport by the CTR-replaceable operations and find the resultant delay. Implicit in this simple approach is that the facilities at each airport can and will accommodate the CTR operations without conflicting with fixed-wing operations. This is not a realistic approach. The CTR's preferred operating mode is not VTOL, although it has that capability. Instead, the preferred mode is turboprop aircraft-like, a 9-degree glide slope (versus 6 degrees for the turboprop) with a 100-foot rollout. So, a runway is needed, albeit a small one. This operational mode invalidates the simple substitution pattern described above.

What is necessary is an airport-by-airport examination of the specific CTR implementation. This requires analyzing runways and airspace, combined with some engineering judgement. Our analysis of these criteria is covered in depth in Chapter 4. In this section, we summarize those results needed for the operations and delay analysis.

CTR-replaceable operations account for 26 percent of all operations, but only 2 percent of available seat-miles flown. The low percentage is due to the relatively small passenger capacity (as compared to a jet), as well as the length of the short-haul flights these aircraft are used on. Assuming a load factor of 67 percent, the 2 percent of the total available seat miles (ASMs) translate to 3 percent of the RPMs. Approximately 26 percent of the operations into the LMINET airports (which are 85 percent of all OAG operations) account for only 2 percent of the corresponding ASMs and 3 percent of the corresponding RPMs. This finding is profound. Although the finding is neither good nor bad, it reflects both the dynamics of the hub-and-spoke system as well as the spatial or geographical characteristics of air traffic demand. However, in another sense the finding also makes a statement of the allocation of the ATM resources. It implicitly states that all operations are in some sense equally valued or costly in terms their load on the ATM system, regardless of the enplanements that each operation carries. The next logical extension is that RPMs or enplanements are lesser valued or are not viewed as a good of an indicator of the value of the ATM resources.

Let us first calculate the number of CTR-dedicated runways needed to handle all the CTR-replaceable operations. We assume that a CTR-dedicated runway can handle 20 operations per hour, and that the runway is open 18 hours per day. Therefore, a CTR-dedicated runway can handle 360 operations per day or 131,400 operations per year. This runway capacity should be interpreted as the optimistic maximum value, meaning that the number of CTR runways needed is actually a minimum.

We must multiply the baseline annual operations for each airport by the percentage of CTR-replaceable flights for each airport. The result is the maximum CTR-replaceable operations per airport. The runways needed to handle these operations are simply the replaced operations divided by 131,400, or the yearly capacity of a CTR runway. We then round up the result to the nearest whole number. Table 2-8 shows these data.

Table 2-8. Maximum Replaced Operations and CTR-Dedicated Runways Needed

	Maximum theoretical replaced operations			CTR-only runways needed		
	2007	2017	2022	2007	2017	2022
Totals	6,376,421	7,658,065	8,116,549	84	9	3
BOS	218,654	238,027	246,781	2	0	0
BDL	54,173	63,865	67,374	1	0	0
HPN	132,522	145,486	150,098	2	0	0
ISP	56,863	61,198	62,863	1	0	0
LGA	88,458	93,317	95,446	1	0	0
JFK	162,867	178,228	185,112	2	0	0
EWR	105,939	122,547	129,018	1	0	0
PHL	189,200	233,522	249,947	2	0	0
BWI	93,345	114,890	122,432	1	0	0
DCA	88,559	93,460	95,766	1	0	0
IAD	227,565	264,913	278,540	2	1	0
GSO	55,167	62,535	64,758	1	0	0
RDU	111,829	122,305	126,639	1	0	0
CLT	160,363	179,346	187,022	2	0	0
ATL	202,402	248,482	263,936	2	0	1
MCO	112,340	146,452	156,659	1	1	0
PBI	59,313	65,732	68,095	1	0	0
FLL	88,345	103,181	108,485	1	0	0
MIA	167,783	214,294	231,716	2	0	0
TPA	89,576	109,885	117,476	1	0	0
MSY	17,381	20,664	21,826	1	0	0
MEM	152,148	185,029	196,782	2	0	0
BNA	27,141	28,440	28,959	1	0	0
SDF	42,985	52,434	55,266	1	0	0
CVG	268,504	347,224	372,865	3	0	0
DAY	48,894	55,548	58,224	1	0	0
CMH	95,063	111,504	115,999	1	0	0
IND	109,303	136,189	144,673	1	1	0
CLE	208,473	253,670	270,209	2	0	1
DTW	142,784	184,092	199,817	2	0	0
PIT	242,117	270,281	281,342	2	1	0
SYR	101,163	110,867	113,669	1	0	0
MKE	115,564	134,436	139,666	1	1	0
ORD	159,512	185,174	195,655	2	0	0
MDW	46,971	55,986	58,966	1	0	0
STL	108,469	132,977	143,257	1	1	0

Table 2-8. Maximum Replaced Operations and CTR-Dedicated Runways Needed (Continued)

	Maximum theoretical replaced operations			CTR-only runways needed		
IAH	138,991	180,809	193,119	2	0	0
HOU	28,186	31,066	32,278	1	0	0
AUS	3,216	3,785	4,031	1	0	0
SAT	17,883	21,344	22,526	1	0	0
DAL	18,972	20,680	21,449	1	0	0
DFW	342,359	425,293	454,448	3	1	0
MSP	127,230	159,922	171,531	1	1	0
MCI	52,210	61,101	64,223	1	0	0
DEN	120,491	138,712	145,971	1	1	0
ABQ	56,938	67,650	71,147	1	0	0
ELP	11,053	12,774	13,287	1	0	0
PHX	76,771	102,685	112,021	1	0	0
SLC	132,132	169,012	180,891	2	0	0
LAS	26,074	35,242	38,195	1	0	0
SAN	74,339	95,076	102,856	1	0	0
SNA	35,386	43,193	46,230	1	0	0
LGB	0	0	0	0	0	0
LAX	273,282	359,848	393,443	3	0	0
BUR	0	0	0	0	0	0
ONT	21,412	29,477	32,343	1	0	0
RNO	13,858	17,044	17,970	1	0	0
SMF	34,366	41,033	42,889	1	0	0
OAK	2,870	3,416	3,624	1	0	0
SFO	97,152	124,215	134,624	1	0	1
SJC	4,799	6,079	6,502	1	0	0
PDX	141,527	172,696	183,008	2	0	0
SEA	173,188	209,734	222,610	2	0	0

To fully implement CTR would require an initial 84 runways by 2007. This means at least one runway at each of the 63 airports under study, except for LGB and BUR. Most airports would need one or two runways, while the previously identified hubs of CVG and DFW would need three of each. In addition, LAX would also need three CTR runways. In another 10 years, growth of the CTR-replaceable flights would grow enough to warrant an additional nine runways; theoretically these would be placed at IAD, MCO, IND, PIT, MKE STL, DFW, MSP, and DEN. Five years of growth, until 2022, would necessitate just three more runways at ATL, CLE, and SFO.

Without changing the standard operating mode to VTOL, implementing the CTRs will necessitate using the same runways currently used by the fixed-wing traffic. Constructing additional runways have been difficult for most airport planning commissions. Although the construction costs of a CTR-dedicated runway may be cheaper than a regular jet runway, the environmental and noise studies will still raise issues. In addition, special siting procedures will be needed to ensure non-interfering operations.

Currently, construction of 85 to 96 new runways is highly unlikely. Instead, let us examine each airport to see what the potential for improvement is. We discuss this part of the study in depth in Chapter 4. We analyzed each of the 64 airports (except Teterboro) for the feasibility of using CTRs. We did an airspace analysis based on runway layouts and standard separation requirements. The focus was on understanding how turboprop aircraft fit into the air traffic flows, how close residential and commercial property abut airport property, and how much space is available for missed approaches. Next, an airport surface analysis was done. We focused on if, and how, stub runways and non-interfering runways were used, and how much unused and underused airport ground space was available. We analyzed this information in its entirety and rated the ease by which a CTR-dedicated runway could be made available at that airport. Table 2-9 summarizes the part of our analysis that is relevant to this part of the study. The table shows how many runways could be available for each of the four types: non-interfering CTR independent, interfering CTR dependant, non-interfering CTR stub runways, and interfering CTR stub runways. For the simulation run, we sited 40 non-interfering CTR-independent runways.

The rules for simulating a CTR-only runway in the model were as follows:

1. At least one independent CTR runway, or
2. At least one independent stub runway, or
3. A combination of two or more dependent CTR runways and dependent stub runways.

These rules should be considered as the minimal for runways needed to implement the CTR. Also, some airports could have more than one CTR runway, but we implemented a maximum of one runway per airport in the model. We also did not include fractional uses of a CTR runway. Of critical importance is our model uses only CTR operations on a stub or independent runway. Vertical operations are possible at almost every airport, but we did not include them in this study. Vertical operation also will be more costly in vehicle costs, but total costs may not be as great.

This shifting of low passenger short-haul traffic from the jet runways to the CTR runways now allows the CTR implementation to be simulated. Airports that now have CTR runways have their low passenger short-haul operations (which implicitly occur on jet runways) reduced by a minimum of CTR-replaceable operations or 131,400, the yearly capacity of a CTR runway.

Table 2-9. Jet and CTR Runways by Airport

	Jet runways	CTR-only runway implemented in model	Independent CTR runways	Dependent CTR runway	Independent stub runway	Dependent stub runway
Totals	209	40	28.9	31.1	4	31
ATL	4	0	0	0	0	0
BOS	5	0	0	0	0	1
BWI	4	1	1	0	0	1
DCA	3	0	0	0	0	1
DEN	5	1	4	0	0	0
DFW	7	1	0	0	1	0
EWR	3	1	1	0	0	0
HPN	2	1	0	1/2	0	1/2
IAD	3	1	1	0	0	1
IAH	4	1	2	0	0	0
JFK	4	0	0	1	0	0
LAX	4	0	0	1	0	0
LGA	2	1	1	1	0	0
LGB	5	1	0	0	0	2
MCO	3	1	1	0	0	0
MDW	5	0	0	0	0	1
MSP	3	1	0	1/2	0	1/2
ORD	7	1	0	1	0	1
SAN	1	1	0	1	0	0
SAT	3	1	2	0	1	0
SEA	2	0	0	1	0	0
SFO	4	1	1	2	0	0
SJC	3	1	0	0	0	2
ABQ	4	1	1	0	0	1
AUS	2	1	3	0	0	0
BDL	3	1	0	0	1	1
BNA	4	0	0	0	0	0
BUR	2	0	0	1	0	0
CLE	4	1	0	1	0	1
CLT	3	1	0	2	0	1
CMH	2	1	1	1	0	1
CVG	3	1	1	1	0	0
DAL	3	0	0	1	0	0
DAY	3	1	1	2	0	0
DTW	5 (6 in 2001)	1	0.95	0.05	0	0
ELP	3	1	0	1	0	1
FLL	3	0	0	0	0	0
GSO	2	0	0	1	0	0
HOU	4	1	0	1	0	2

Table 2-9. *Jet And CTR Runways by Airport (Continued)*

	Jet runways	CTR-only runway implemented in model	Independent CTR runways	Dependent CTR runway	Independent stub runway	Dependent stub runway
IND	3	1	0	0	0	2
ISP	4	0	0	0	0	1
LAS	4	0	0	0	0	0
MCI	3	1	1	0	0	0
MEM	4	0	0	0	0	0
MIA	3	0	0	1	0	0
MKE	5	1	1	0	0	1
MSY	3	1	1	0	0	1
OAK	4	0	0	0	0	1
ONT	2	1	1	0	0	0
PBI	3	0	0	0	0	1
PDX	3	0	0	1	0	0
PHL	4	1	0	1	0	2
PHX	2	1	1	0	0	0
PIT	4	1	0	2	0	0
RDU	3	1	1	0	1	0
RNO	3	0	0	1	0	0
SDF	3	1	0	1	0	1
SLC	4	1	0	2	0	1
SMF	2	1	0	2	0	0
SNA	2	0	0	0	0	0
STL	5	0	0	0	0	1
SYR	2	1	1	0	0	0
TPA	3	0	0	0	0	0

THE CTR DELAY CASE

The CTR is "implemented" in LMINET by subtracting the one-runway, CTR-replaceable operations from the total operations. Of course, this is the optimistic case because it is based on the assumption that operations between the CTR and the fixed-wing aircraft will not interfere. Table 2-10 shows the theoretical maximum CTR-replaceable operations and the realistic replaceable operations for each airport. [3]

[3] The theoretical replaceable operations are the total of all turbojet and turboprop flights of 500 miles or less into a particular airport. Implicit in this measure is that runway capacity at that airport is enough to handle new operations by new CTR aircraft into that airport. The realistic replaceable operations are the part of the theoretical operations that a particular airport could handle if a CTR-only dedicated runway were built.

Table 2-10. Replaceable Operations by Airport

	Theoretical replaceable operations			Realistic replaceable operations		
Year	2007	2017	2022	2007	2017	2022
Totals	6,376,421	7,658,065	8,116,549	3,875,629	4,179,039	4,258,072
BOS	218,654	238,027	246,781	0	0	0
BDL	54,173	63,865	67,374	54,173	63,865	67,374
HPN	132,522	145,486	150,098	131,400	131,400	131,400
ISP	56,863	61,198	62,863	0	0	0
LGA	88,458	93,317	95,446	88,458	93,317	95,446
JFK	162,867	178,228	185,112	131,400	131,400	131,400
EWR	105,939	122,547	129,018	105,939	122,547	129,018
PHL	189,200	233,522	249,947	131,400	131,400	131,400
BWI	93,345	114,890	122,432	93,345	114,890	122,432
DCA	88,559	93,460	95,766	0	0	0
IAD	227,565	264,913	278,540	131,400	131,400	131,400
GSO	55,167	62,535	64,758	55,167	62,535	64,758
RDU	111,829	122,305	126,639	111,829	122,305	126,639
CLT	160,363	179,346	187,022	131,400	131,400	131,400
ATL	202,402	248,482	263,936	0	0	0
MCO	112,340	146,452	156,659	112,340	131,400	131,400
PBI	59,313	65,732	68,095	59,313	65,732	68,095
FLL	88,345	103,181	108,485	0	0	0
MIA	167,783	214,294	231,716	131,400	131,400	131,400
TPA	89,576	109,885	117,476	0	0	0
MSY	17,381	20,664	21,826	0	0	0
MEM	152,148	185,029	196,782	0	0	0
BNA	27,141	28,440	28,959	0	0	0
SDF	42,985	52,434	55,266	0	0	0
CVG	268,504	347,224	372,865	131,400	131,400	131,400
DAY	48,894	55,548	58,224	48,894	55,548	58,224
CMH	95,063	111,504	115,999	95,063	111,504	115,999
IND	109,303	136,189	144,673	109,303	131,400	131,400
CLE	208,473	253,670	270,209	131,400	131,400	131,400
DTW	142,784	184,092	199,817	131,400	131,400	131,400
PIT	242,117	270,281	281,342	131,400	131,400	131,400
SYR	101,163	110,867	113,669	101,163	110,867	113,669
MKE	115,564	134,436	139,666	115,564	131,400	131,400
ORD	159,512	185,174	195,655	0	0	0
MDW	46,971	55,986	58,966	0	0	0
STL	108,469	132,977	143,257	0	0	0
IAH	138,991	180,809	193,119	131,400	131,400	131,400
HOU	28,186	31,066	32,278	28,186	31,066	32,278
AUS	3,216	3,785	4,031	3,216	3,785	4,031

Table 2-10. Replaceable Operations by Airport (Continued)

Year	2007	2017	2022	2007	2017	2022
	Theoretical replaceable operations			Realistic replaceable operations		
SAT	17,883	21,344	22,526	17,883	21,344	22,526
DAL	18,972	20,680	21,449	18,972	20,680	21,449
DFW	342,359	425,293	454,448	131,400	131,400	131,400
MSP	127,230	159,922	171,531	127,230	131,400	131,400
MCI	52,210	61,101	64,223	52,210	61,101	64,223
DEN	120,491	138,712	145,971	120,491	131,400	131,400
ABQ	56,938	67,650	71,147	56,938	67,650	71,147
ELP	11,053	12,774	13,287	11,053	12,774	13,287
PHX	76,771	102,685	112,021	76,771	102,685	112,021
SLC	132,132	169,012	180,891	131,400	131,400	131,400
LAS	26,074	35,242	38,195	0	0	0
SAN	74,339	95,076	102,856	74,339	95,076	102,856
SNA	35,386	43,193	46,230	0	0	0
LGB	0	0	0	0	0	0
LAX	273,282	359,848	393,443	0	0	0
BUR	0	0	0	0	0	0
ONT	21,412	29,477	32,343	21,412	29,477	32,343
RNO	13,858	17,044	17,970	13,858	17,044	17,970
SMF	34,366	41,033	42,889	34,366	41,033	42,889
OAK	2,870	3,416	3,624	0	0	0
SFO	97,152	124,215	134,624	97,152	124,215	131,400
SJC	4,799	6,079	6,502	0	0	0
PDX	141,527	172,696	183,008	131,400	131,400	131,400
SEA	173,188	209,734	222,610	131,400	131,400	131,400

An interesting measure of an airport's ability to accept the CTR is simply the ratio of the realistic CTR-replaceable operations to the theoretical CTR-replaceable operations. Table 2-11 shows this measure, defined as the operations capture ratio (OCR). The measure reflects the following key ideas:

1. When the measure is 0 percent, no room exists for a CTR-dedicated runway.
2. When this ratio is mathematically undefined, there are no short-haul non-jet flights into that airport.
3. When the non-zero ratio tends towards 100 percent, one CTR-dedicated runway is sufficient to meet the demand at that airport.

4. When the non-zero ratio tends towards 0, the CTR-dedicated runway is above capacity and the growth in CTR traffic is being handled on the runways designed for fixed-wing aircraft.

The national average starts at 57 percent in 2007 and ends at 47 percent in 2022. This means that the minimal set of CTR-dedicated runways will handle on average a little bit more than half of the CTR operations. The drop from 57 percent to 47 percent also is indicates that the CTR-replaceable operations are growing at a much lower rate the other longer-haul or jet operations.

Table 2-11. Operations Capture Ratio (in Percent)

Airport	2007	2017	2022
	53	48	47
BOS	0	0	0
BDL	100	100	100
HPN	99	90	88
ISP	0	0	0
LGA	100	100	100
JFK	0	0	0
EWR	100	100	100
PHL	69	56	52
BWI	100	100	100
DCA	0	0	0
IAD	58	50	47
GSO	0	0	0
RDU	100	100	100
CLT	82	73	70
ATL	0	0	0
MCO	100	90	84
PBI	0	0	0
FLL	0	0	0
MIA	0	0	0
TPA	0	0	0
MSY	100	100	100
MEM	0	0	0
BNA	0	0	0
SDF	100	100	100
CVG	49	38	35
DAY	100	100	100
CMH	100	100	100
IND	100	96	91
CLE	63	52	49
DTW	92	71	66

Table 2-11. Operations Capture Ratio (Continued)
(in Percent)

Airport	2007	2017	2022
PIT	54	49	47
SYR	100	100	100
MKE	100	98	94
ORD	82	71	67
MDW	0	0	0
STL	0	0	0
IAH	95	73	68
HOU	100	100	100
AUS	100	100	100
SAT	100	100	100
DAL	0	0	0
DFW	38	31	29
MSP	100	82	77
MCI	100	100	100
DEN	100	95	90
ABQ	100	100	100
ELP	100	100	100
PHX	100	100	100
SLC	99	78	73
LAS	0	0	0
SAN	100	100	100
SNA	0	0	0
LGB	undefined	undefined	undefined
LAX	0	0	0
BUR	undefined	undefined	undefined
ONT	100	100	100
RNO	0	0	0
SMF	100	100	100
OAK	0	0	0
SFO	100	100	98
SJC	100	100	100
PDX	0	0	0
SEA	0	0	0

The results of implementing the CTRs are profound. Although these results should be viewed as the optimal of optimal results, they make a solid case for the CTR on the basis of reducing delays. These results are based on minimizing the delay as well as maintaining the same number of operations. The operations replaced by the CTR are not replaced with additional long-haul flights, so the delay is minimized. Table 2-12 shows the summary data. With CTRs, the delay in 2022 is at the same point it is in 2007 baseline case. The number of operations is down, but the simulation is based on operations on jet runways. The comparison of the delay and the operations metrics are show in Figures 2-2 to 2-4.

Table 2-12. Summary of CTR LMINET Results

	1997	2007	2017	2022
Total runway operations (millions)	20.932	25.779	31.173	33.106
Total OAG runwayoperations (millions)	16.991	21.572	26.689	28.515
Total RPMs (billions)	N/A	932.8	1495.4	1867.7
Average delay per total operation (minutes)	6.71	9.08	18.27	22.83
Total delay minutes (millions)	140	234	570	756

The figures also visually display the operations—delay time tradeoff. The simulation represents all the jet traffic and the CTR replaceable traffic that can not be handled on new CTR dedicated runways. Implicit in this statement is the slots left by the accommodated CTR replaceable flights have not been filled. Operations and delay are at the minimum points. For any year, there is a gap between operations and delay of the two cases. If the operations were to increase, the delay would then also rise. Although this relationship is non linear, it is easy to think of it as a sliding scale were as the operations are moved up, the corresponding delay increases. Therefore, the case where operations are maximized is also where delay is the largest.

The trade off range, in terms of the operations is very small. The theoretical CTR replaceable operations are about 30 percent of the 64 airports modeled in LMINET. The realistic CTR replaceable operations are approximately half of those.

Figure 2-2. OAG Operations Comparison

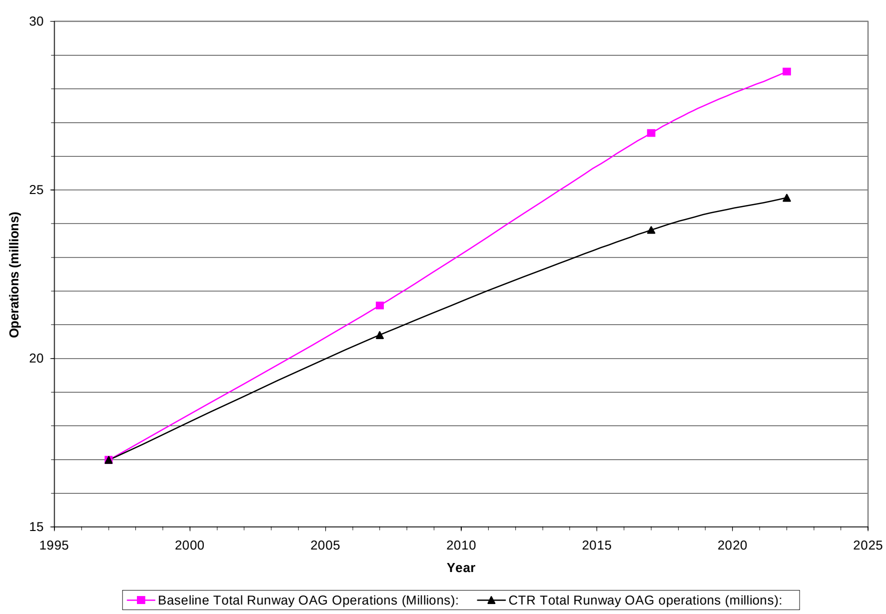


Figure 2-3. Total RPMs Comparisons

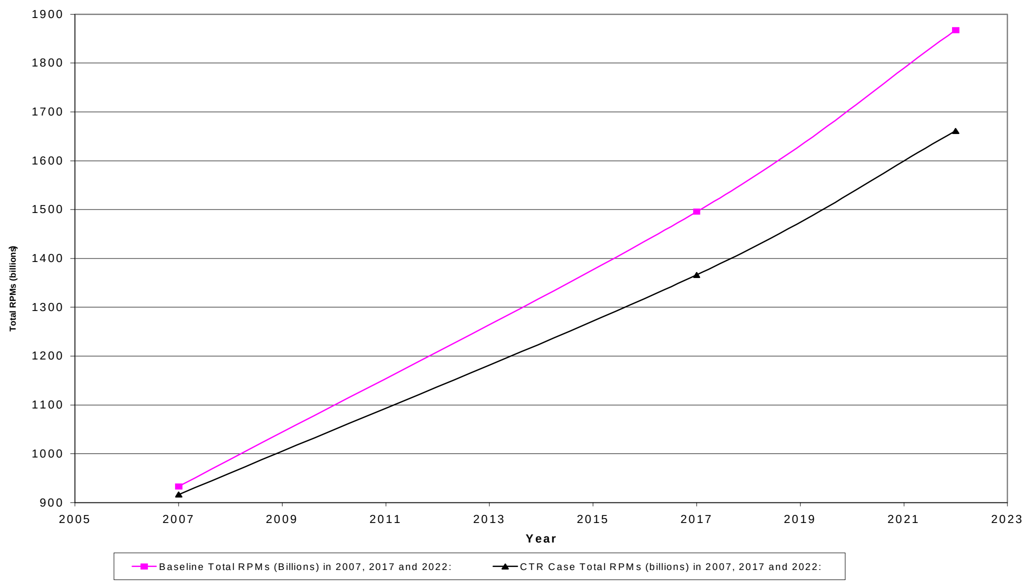


Figure 2-4. Total Operations Comparison

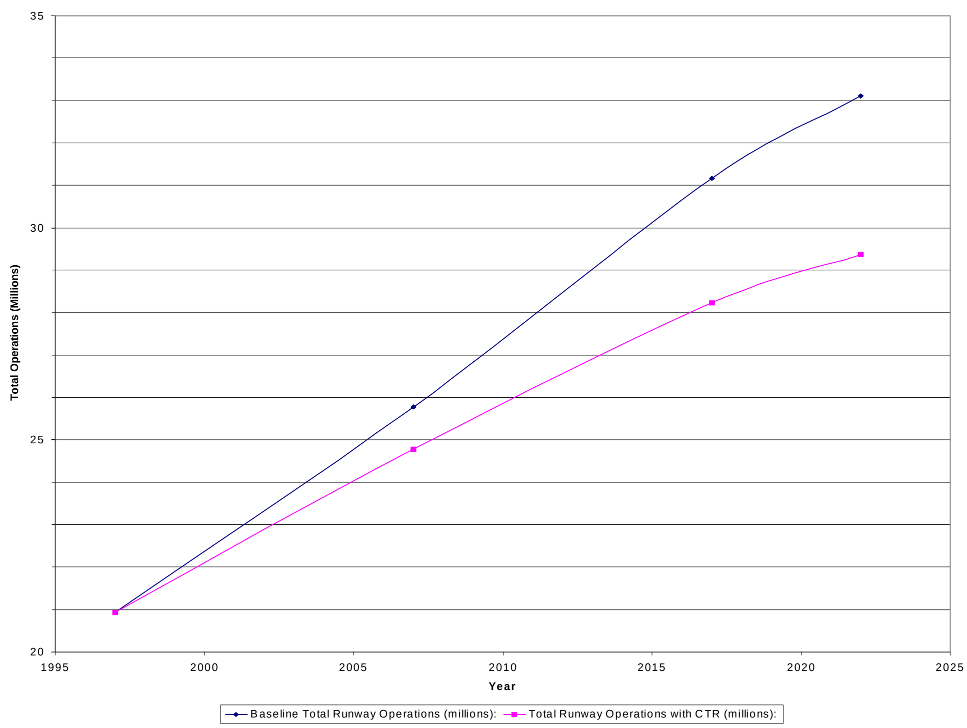
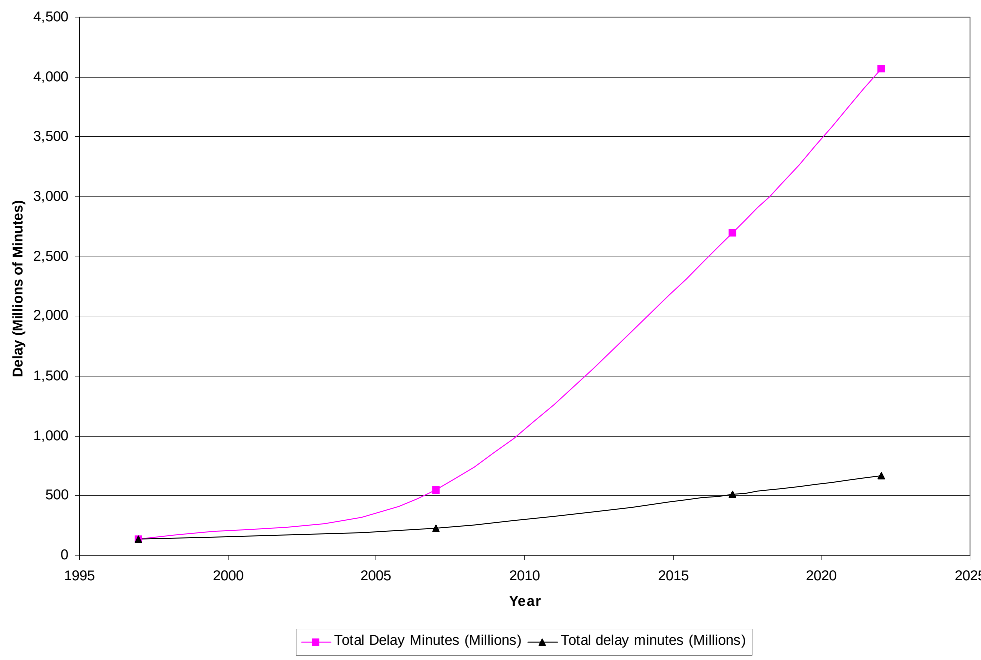


Figure 2-5. Comparisons Total Delay Minutes



Gap Analysis

There will be a tradeoff between operations and delay time. The simulation represents all the jet traffic and the CTR-replaceable traffic that cannot be handled on new CTR-dedicated runways. Implicit in this simulation is that the slots left by the accommodated CTR-replaceable flights have not been filled. Operations and delay are at the minimum points. For any year, a gap exists between operations and delay of the two cases. If the operations were to increase, the delay also would rise. Although this relationship is nonlinear, it is similar to a sliding scale in which as the operations are moved up, the corresponding delay increases. Therefore, the case where operations are maximized also is where delay is the largest.

The tradeoff range, in terms of the operations, is very small. The theoretical CTR-replaceable operations are about 26 percent of the 64 airports modeled in LMINET. The realistic CTR-replaceable operations move from 53 percent of the theoretical replaceable operations in 2007 to 47 percent in 2022.

Table 2-13 shows the operations gap and Figure 2-6 shows it graphically. Starting with the baseline results, the CTR operations are counted using the system-level statistics and the following set of assumptions:

1. LMINET operations account for 85 percent of total operations.

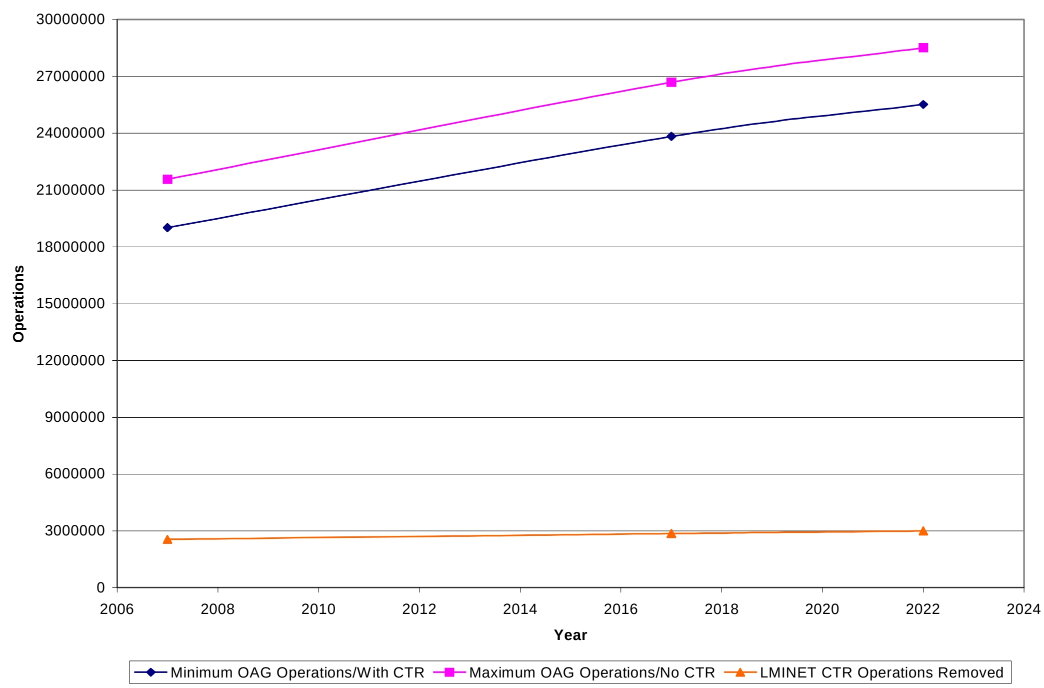
2. 29.1 percent of the operations are CTR replaceable.

3. System-level OCRs are 0.53, 0.48, 0.47 for the years 2007, 2017, 2022, respectively.

Table 2-13. Operations Gap Analysis

	2007	2017	2022
Baseline Total operations	25,779,000	31,173,000	33,106,000
Baseline OAG operations	21,572,000	26,689,000	28,515,000
Short-haul Turboprop/jet operations removed	2,555,883	2,863,836	2,996,028
CRT implemented with no operations replacement			
Minimum total runway operations	23,223,117	28,309,164	30,109,972
Minimum OAG runway operations	19,016,117	23,825,164	25,518,972
Percentage of total runway operations removed	9.9	9.2	9.1
Percentage of OAG runway operations removed	11.9	10.7	10.5
CRT implemented with maximum operations replacement			
Maximum total runway operations	28,334,883	34,036,836	36,102,028
Maximum OAG runway operations	24,127,883	29,552,836	31,511,028
Percentage of total runway operations added	9.9	9.2	9.1
Percentage of OAG runway operations added	11.9	10.7	10.5

Figure 2-6. CTR Operations Gap



A similar gap also exists in the RPMs. The major difference is that the RPM gap narrows over time, due to two effects:

- Average stage length per flight is increasing over time
- Longer haul flights are increasing at a faster rate than the CTR-replaceable flights.

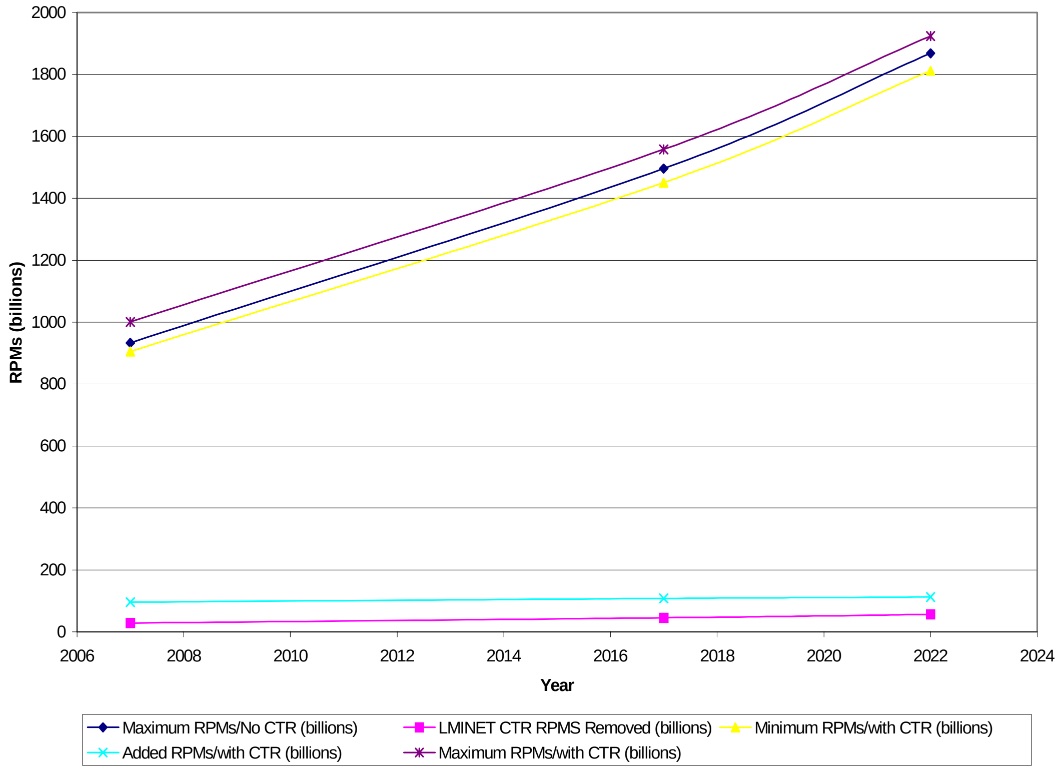
Additional operations and their corresponding RPMs are not “free.” The cost of them is paid for by an increase in delay. Replacing the operations removed by CTRs with jet operations allows a maximum increase in RPMs of 8.7 percent, 5.7 percent, and 4.6 percent, for the years 2007, 2017, and 2022, respectively.[4] Table 2-14 and Figure 2-7 show these results.

Table 2-14. RPM Gap Analysis

	2007	2017	2022
Baseline total RPMs (billions)	932.8	1,495.4	1,867.7
CTR-replaceable RPMs (billions)	14.8	21.5	26.3
Added RPMs from replaced operations (billions)	95.8	107.4	112.4
RPM replacement rates	6.5	5.0	4.3
CTR implemented RPMs with CTR but without operations replacement (billions)			
Minimum RPMs with CTR	918.0	1,473.9	1,841.4
Percentage RPM decrease	1.6	1.4	1.4
CTR implemented RPMs with maximum replacement operations			
Maximum RPMs with CTR (billions)	1,013.8	1,581.3	1,953.8
Percentage RPMs increase with CTR (billions)	8.7	5.7	4.6

[4] The assumption is the national average of 75 passengers per aircraft per replaced operation and an average stage length of 500 miles. Thus, each replaced operation represents 37,500 RPMs.

Figure 2-7. CTR RPM Gap



Summary

The benefits of CTR implementation extend to reducing delay for all users of an airport, not just those to those passengers actually flying on a CTR. Implementation of the CTR (and its appropriate infrastructure) presents the possibility to *either* reduce delay *or* add capacity to the NAS. Although implementing CTRs reduces the average national delay per operation, the benefits will be mostly localized. Those airports with OCR consistently above 90 percent (through 2022) have the option of offloading all or nearly all turbojet and turboprop traffic to a CTR-dedicated runway.

The 26 airports with OCR above 90 percent are BDL, HPN, LGA, EWR, BWI, RDU, MSY, SDF, DAY, CMH, IND, SYR, MKE, HOU, AUS, SAT, MCI, DEN, ABQ, ELP, PHX, SAN, ONT, SMF, SJC, and SFO. At the other end of the scale, 25 airports cannot implement CTRs in standard operating mode because simply no space is available for the dedicated runway. Any CTR operations at these airports *must* be strictly in the vertical mode. The 25 airports are BOS, ISP, TEP, JFK, DCA, GSO, ATL, FLL, PBI, MIA, TPA, MEM, BNA, MDW, STL, DAL, LAS, SNA, LGB, LAX, BUR, RNO, OAK, PDX, and SEA. Results at the remaining 19 airports will be mixed. CTRs can be implemented at these airports, but the question may be: Is the construction or infrastructure investment worth it?

When the local effects are summarized and analyzed from a national perspective, the tradeoff of operations to RPMs seems somewhat unbalanced. The percentage of operations removed is greater that the percentage increase in RPMs added by those same operations. When this effect is coupled with the increasing delay per operation, as the CTR-replaceable operations are replaced with jet operations, maximizing both operations, RPMs, and hence delay, obviously is not the wisest choice. There is an increasing marginal effect to the additional operations. The best choice is to raise the operations, and hence the RPMs, until an acceptable level of delay is reached.

How such a scheme would be implemented in a deregulated air transportation system is another question. One possibility is that a carrier could add a non-interfering CTR operation at the same time as adding a new jet operation. In some sense, the carrier has captured that jet runway slot for themselves. Some airports could cap jet runway operations and allow only CTR operations, or fix them at some ratio. However, slot controls at airports are vanishing, and postponing their disappearance, or resurrecting them at CTR-enabled airports, is unlikely.

The hub-specific nature of the benefits means that the CTR can be a vehicle implemented as a strategic choice by the carriers. Those airports with high OCRs and dominant hub ownership are the most likely candidates for implementation. From a strategic point of view, those hubs with high OCRs and no dominant hub ownership may be a target for expanding operations using the CTR as the vehicle of choice, or turning it into a dominant hub.

Chapter 3
CTR Economics

The CTR is a different vehicle for a different concept. As such, traditional economic measures for analyzing the design and performance of fixed-wing aircraft present only a part of the complete picture. In this chapter, we present the traditional manufacturing and operation economics analysis. We also examine new measures and a different framework, which capture the unique role that the CTR can play.

Manufacturing Economics

Currently, the CTR under consideration in this analysis exists as a conceptual vehicle. The data we used in this analysis were first presented in the CTRDAC study published in 1995. They specified a CTR with the following characteristics:

- 40-passenger capacity
- Instrument flight rules (IFR) capability
- Cruise speed of 350–400 miles per hour
- Maximum ceiling of 32,000 feet
- Design range of 600 nautical miles (690 statute miles) with full passenger load
- Maximum range of more than 1,000 nautical miles (1,151 statute miles) with IFR reserves.

The 1995 study also presents a set of costs. We based our analysis on these costs.The costs were based on the following assumptions:

- Government and industry sharing research, development, and demonstration program costing $600 million ($678 million in year 2000 dollars)
- CTR manufacturing program starting in 2003, with first deliveries in 2007
- Manufacturing development cost of $1.2 billion ($1.36 billion in year 2000 dollars)
- Selling price of $18.5 million per aircraft ($20.9 million in year 2000 dollars), with a breakeven point of 506 aircraft sales

- A learning curve structure of 85 percent before breakeven and 90 percent after.

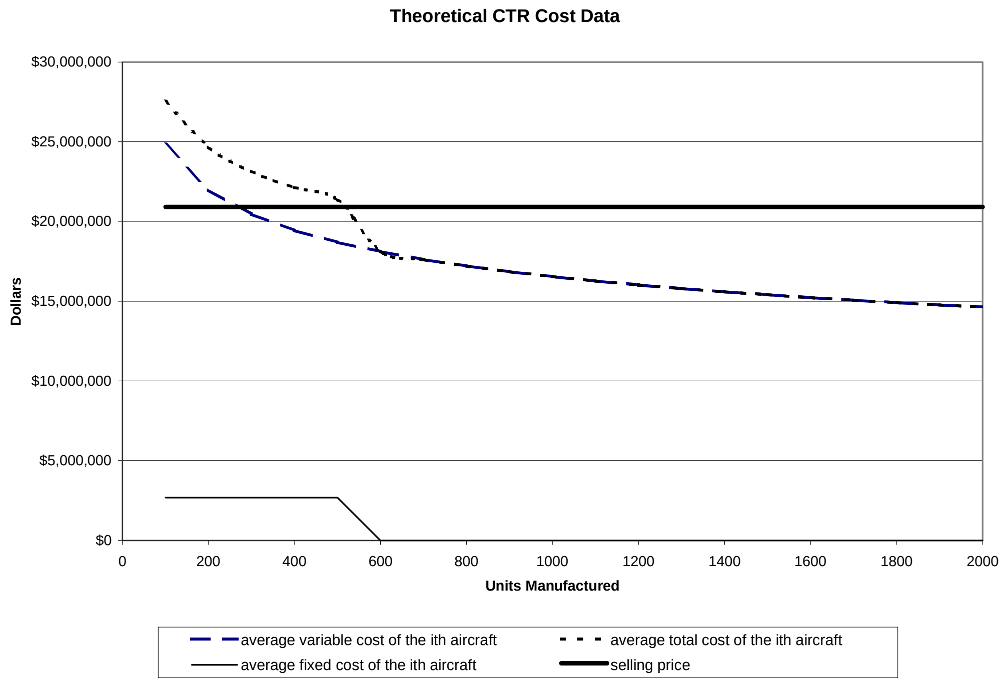
These cost factors, taken from the CTRDAC study represent considerable improvement over current cost trends. The improvements presumably reflect projected technology levels.

We used these data to calculate a cost-quantity table (Table 3-1) and its associated graph (Figures 3-1). The actual derivation of the variable cost is shown in Appendix A. To a large degree, the cost-quantity curve determines the manufacturer's willingness to build the vehicle and the potential profits from the project. A minimum number of aircraft sales usually is required to launch a new vehicle line. In this case, the breakeven point is 506 aircraft over the first 10 years, at almost $21 million each. Although the graphs exaggerate early manufacturing costs somewhat, one fact is abundantly clear: Once the breakeven is reached, the potential for profit exists if the demand for 2,000 units is real.

Table 3-1. Cost Quantity for Proposed CTR (in dollars)

No. of aircraft	Average variable cost of i^{th} aircraft	Fixed cost of i^{th} aircraft	Average cost of i^{th} aircraft
100	24,844,621	2,680,946	27,525,567
200	21,980,006	2,680,946	24,660,952
300	20,459,977	2,680,946	23,140,922
400	19,445,685	2,680,946	22,126,631
500	18,693,697	2,680,946	21,374,643
600	18,100,917	0	18,100,917
700	17,614,417	0	17,614,417
800	17,203,574	0	17,203,574
900	16,849,146	0	16,849,146
1,000	16,538,291	0	16,538,291
1,100	16,262,032	0	16,262,032
1,200	16,013,859	0	16,013,859
1,300	15,788,908	0	15,788,908
1,400	15,583,454	0	15,583,454
1,500	15,394,584	0	15,394,584
1,600	15,219,981	0	15,219,981
1,700	15,057,771	0	15,057,771
1,800	14,906,419	0	14,906,419
1,900	14,764,653	0	14,764,653
2,000	14,631,406	0	14,631,406

Figure 3-1. Theoretical CTR Cost Data



OPERATING ECONOMICS

The fundamental concept of aircraft ownership is that operators will purchase new aircraft only if they can make a profit with those aircraft. As designed, the CTR is a functional replacement for turboprops and turbojets. In fact, when the CTR is actually built, turbojets and regional jets probably already will have replaced most turboprop aircraft. Table 3-2 shows the makeup of most of the regional airline turbojet/turboprop fleet that the CTR hopes to supplant. Table 3-3 shows the standard cost comparison data for models in use by major U.S. airlines.

Table 3-2. Characteristics of Current Turbojet/Turboprop Fleet

Manufacturer	Model	Number in U.S. service	Average number of seats
Saab	340	272	34
Raytheon	1900	247	19
Embraer	Brasilia	203	30
Bombardier	Dash 8-100/200	159	37
Bombardier	RL	140	50
Beech	BE1900	130	19
BAE	J31/J32	121	19
Aerospatiale	ATR42	79	39

Table 3-2. Characteristics of Current Turbojet/Turboprop Fleet (Continued)

Manufacturer	Model	Number in U.S. service	Average number of seats
Embraer	ERJ145	63	50
Aerospatiale	ATR72	60	64
BAE	J41	57	29
Bae/Avro	146/RJ85	36	80
Fokker	F28	20	62
FAI	SA227	18	37
Convair	CV-580	3	50

Table 3-3. Cost Comparison

Aircraft	Aircraft operating cost per block hour (dollars)	Aircraft operating cost per ASM (dollars)	Average stage length (miles)
Canadair RJ145-100	1,984	0.1467	337
Embraer 145	928	0.0696	437

One of the major assumptions of the CTRDAC study is that CTRs will be more expensive to operate, and that the higher operating cost must be reflected in the fares paid by passengers. Another case is worth examining. CTR use will be for short-haul flights: point-to-point but also hub-to-spoke and spoke-to-hub. From this point of view, the fare yields, and hence the ticket prices, are more complex than the cost of the aircraft used. The ticket price reflects a variety of factors, including hub size, level of competition, who the competitors are, and the aircraft equipment used. Table 3.4 shows the average one-way fare by stage length for a variety of hubs. From the operators' point of view, the issue is whether the CTR increases the operators' total profits when it operates out of the hubs and the operator charges the prices shown in the table.

Table 3-4. One-Way Fares by Hub and Stage Length (dollars)

Hub	0–249 miles	250–499 miles
Large hub average	102	110
Medium hub average	86	92
Small hub average	118	132
CLT	144	194
CVG	157	187
PIT	177	175
DCA	126	162
MSP	174	159
PHL	175	158
LGA	112	147

Table 3-4. One-Way Fares by Hub and Stage Length (dollars) (Continued)

Hub	0–249 miles	250–499 miles
ORD	102	134
EWR	136	131
DEN	98	130
BOS	111	127
DTW	92	124
ATL	144	118
MIA	81	114
MCO	71	108
JFK	92	107
DFW	71	101
IAH	75	99
STL	70	99
TPA	66	99
IAD	110	99
BWI	150	95
SLC	98	88
SEA	67	82
SFO	67	72
LAS	56	61
LAX	57	60
PDX	92	56
SAN	64	56
PHX	78	55

DEMAND FOR CTRS

The demand for CTRs will be the factor that decides whether this aircraft will be commercially manufactured. The first reason for CTR demand will be to replace turboprop and turbojet aircraft. Although this source of demand is important, new and different uses for the CTR will be necessary to increase the demand and reduce the final manufacturing costs.

An in-depth analysis of each of the following scenarios was beyond the scale and scope of this project, but they deserve mention as further capabilities and potential uses of the CTR.

Scenario 1: Hub Extension Strategy

Most U.S.-based carriers have adopted a hub-and-spoke strategy. In certain geographic markets, multiple airports are located within reasonable travel times. Air carriers can use the CTR as a connecting aircraft between these close airports and “extend” their hub from one airport to another. Specific U.S. markets where this strategy could be implemented are as follows:

- Washington, DC, metropolitan area: DCA, BWI, IAD
- New York City metropolitan area: EWR, LGA, JFK, ISP, HPN
- Northern California metropolitan area: OAK, SFO, SJC, SAC
- Southern California metropolitan area: LAX, LGB, BUR, ONT, SNA
- Texas hubs: IAH, HOU, DFW, DAL, SAT, ELP, AUS
- Chicago metropolitan area: ORD, MDW.

Also this strategy could also be implemented in foreign markets:

- London metropolitan area: LHR, LGW, LTN, STN
- Rome metropolitan area: FCO, CIA
- Paris metropolitan area: CDG, ORY.

Scenario 2: Airport Shuttle System

The hub extension strategy is based on the premise that carriers will operate CTR service for their own passengers. Broadening this concept leads to a shuttle service between those same airports. The difference is that this service may be owned and operated by an airport authority or by a private firm that is separate from carriers.

Scenario 3: Airport Allocation System

In some distinct geographic markets, multiple airports share national and international traffic. One method for reducing the mix of aircraft—and hence the delay—is to designate one airport for international traffic and the others for domestic traffic. The CTR would be used to shuttle passengers between the domestic and international airports. This allocation could occur at the following sets of airports:

- JFK and LGA in the New York metropolitan area
- DCA and IAD in the Washington metropolitan area
- OAK and SFO in the northern California metropolitan area
- LAX and LGB in the southern California metropolitan area
- IAH and HOU in the Houston metropolitan area

- DFW and DAL in the Dallas metropolitan area.

Scenario 4: Long Short-Haul Shuttle Service

The CTR replacement analysis looked at replacing turboprops and turbojets only on routes of 500 miles or less. This analysis overlooks scheduled jet shuttle services offered on the East and West coasts. Our analysis of the OAG shows a shuttle service operated between LAX and SFO, using jets with more than 48 seats. A similar shuttle system exists on the East coast, with BOS and DCA as the endpoints in the network. The CTR cannot match the cruise speed of these aircraft. Because the flight times of these operations are relatively short; however, the CTR may be able to improve on the gate-to-gate time, which includes the effects of runway delay.

Scenario 5. Small Markets Not Examined

Our analysis of operations and delays was based on the LMINET 64 airport model. Although these airports account for 85 percent of airport operations, the CTR may play a pivotal role in providing access to large markets at other airports. Several small-market cities serve these 64 airports by jet. The CTR may be able to substitute into some of these airports. In addition, as population grows, areas that lack service will reach the minimal threshold for new service. The CTR then becomes an option for these markets.

SECONDARY BENEFITS OF CTR USE

CTR has a set of secondary benefits. These benefits are especially important; the usual direct benefits of decreases in costs will not be applicable because the CTR will have higher operating costs than the fixed-wing aircraft they replace. The problem with the secondary benefits is that do not totally accrue to the owners or operators of the CTRs.

Reduction in Delay to Passengers on Fixed-Wing Aircraft

As envisioned, the CTR transports passengers who had been on turboprop or turbojet aircraft operating on jet runways. Removing some of these passengers and their associated aircraft reduces delay time for passengers and aircraft that continue to use jet runways. This positive benefit is fully captured only if one, and only one, carrier operates out of a hub. To the extent that multiple carriers operate out of a hub, this benefit partially accrues to all operators, regardless of whether they operate CTRs. The benefits accrue to passengers as lesser flight times and to operators as lower costs.

This reduction in delay time also results in an increased mobility for CTR and non-CTR flying passengers. This reduced delay time is related directly to decreased gate-to-gate time. Some of the foregoing scenarios should result in a larger increase in mobility. This is because of a decrease in aspects of travel time other than flight delay.

Increase in Operations

Removing short-haul traffic allows for some combination of reduced delay (if short-haul operations are not replaced) and increased operation (if short-haul operations are replaced with long-haul flights). When operations increase, the flying public benefits because they have more opportunities to travel; at the same time, the operators of those additional flights benefit economically from flying those flights. That benefit accrues to the carrier, which may or may not be the CTR operator, that now uses that takeoff/landing slot.

CTR manufacturing results in increased employment in manufacturing and industry, including pilots, flight attendants, and support staff. The payments to these employees increase the gross domestic product (GDP). To accurately account for these benefits, we must calculate the corresponding employment decreases from turboprop/turbojet production. There also will be a one-time increase in employment and payments for construction of new infrastructure for CTR use: landing strips, terminals, apron extensions or conversions, and the like.

In addition, CTRs will be fully state-of-the-art electronically equipped, which enables more rapid deployment of new ATM technologies—partly because of the introduction of new CTRs themselves and partly because they will be replacing older turboprops and turbojets. These ATM technologies are likely to come with new and updated FAA rules and procedures for handling CTR streams of traffic, which may result in streamlined separation rules for aircraft flows that do not apply to turboprop aircraft.

The CTR embodies a new and unproven technology. Bringing this project to fruition will represent a major advance in technology. This technology—in and of itself, as well as the processes used to perfect the technology—will have spillover benefits to other industries. The spillover may include new materials and new manufacturing techniques.

Chapter 4
Airport Feasibility Analysis

INTRODUCTION

To help determine if CTRs would be viable nationally, we examined some of the busiest airports in the United States. If CTRs can help alleviate congestion at the busiest airports and accommodate growing air travel demand, that would indicate viability. In examining these busy airports, we tried to determine how easily CTRs could be added to the airport's operations. Our goal was to introduce CTRs in the airports' fleet mix while increasing or holding constant airport capacity[1]—and incurring minimal introduction cost.

CHOICE OF STUDY AIRPORTS

The 64 LMINET airports make up our study set. The 64 LMINET airports, which capture 85 percent of total U.S. enplanements, comprise the FAA's 57 "pacing airports" plus a few additional airports.[2] "Pacing airports" are airports that the FAA has used for studying flight operations in the NAS. Most flight delays in the NAS occur at LMINET airports.

Tables 4-1 and 4-2 compare the operations and enplanements, respectively, at LMINET airports and the NAS pacing airports.

Table 4-1. Total Operations at LMINET Airports Versus NAS Pacing Airports

		Operations (in millions)			Growth rate (%)	
	Count	1997	2005	2015	1997–2005	2005–2015
Large hubs	29	13.8	16.2	20.3	2.07	2.27
Medium hubs	42	9.3	11.0	13.1	2.10	1.75
Small hubs	68	8.4	9.4	10.4	1.37	1.02
Nonhub towers	312	32.3	35.5	38.9	1.19	0.92
Total	451	63.9	72.1	82.6	1.53	1.37
LMINET airports	64	20.9	24.6	30.3	2.06	2.11

[1] Capacity is in terms of enplanements.

[2] The 64 LMINET airports account for 84.9 percent of total domestic enplanements and 85 percent of total domestic operations, as reported in DOT's T-100 data.

Table 4-2. Total Enplanements at LMINET Airports Versus NAS Pacing Airports

	Count	Enplanements (in millions)			Growth rate (%)	
		1997	2005	2015	1997–2005	2005–2015
Large hubs[a]	29	430.2	577.1	806.8	3.74	3.41
Medium hubs[b,c]	42	139.2	193.7	270.1	4.21	3.38
Small hubs[d]	68	43.5	57.3	73.4	3.52	2.50
Nonhub towers	310	16.6	20.7	26.0	2.80	2.28
Total	449	629.5	848.9	1,176.4	3.81	3.32
LMI airports	64	534.3	722.3	1,008.2	3.84	3.39
Share (%)	—	84.9	85.1	85.7	—	—

Source: DOT, *Aerospace Forecasts*, *Fiscal Years 1999–2010*, Report No. FAA-APO-99-1 (Washington, D.C.: Federal Aviation Administration, Office of Aviation Policy and Plans, Statistics and Forecast Branch, 1999).

[a] > 1.0 percent of total enplanements.

[b] > 0.25 percent of total enplanements.

[c] The 42 medium-hub airports are ABQ, ANC, AUS, BDL, BNA, BUF, BUR, CLE, CMH, COS, DAL, ELP, FLL, GEG, HOU, IAD, IND, JAX, MCI, MDW, MEM, MKE, MSY, OAK, OGG, OKC, OMA, ONT, PBI, PDX, RDU, RNO, RSW, SAT, SDF, SJC, SJU, SMF, SNA, TUL, TUS, and GUM.

[d] > 0.05 percent of total enplanements.

METHODOLOGY

We examined each of the 64 airports separately. We attempted to determine if the airport had sufficient air and ground space to accommodate CTR operations—preferably independent operations because independent CTR operation offers the best hope for increasing capacity at an airport. We rated the ease with which the airport could be "converted" to a CTR-serving airport and the likely effect on capacity if it were. We paid particular attention to the potential neighborhood noise impacts of adding CTR runways; we considered the potential for a significant increase in residential neighborhood noise to be enough to prevent adding a CTR runway.

We used the following assumptions:

- A CTR runway would require a minimum of 800' supporting touch-down weight and 1,000' total planned length.
- CTR runways must be paved.
- CTRs can "dock" at a CTR-only terminal that is removed from the main terminal or join the taxi queue to the main terminals, although much of the advantage of CTR operation is negated if the CTR is required to mix with the existing hub-and-spoke operation.
- A CTR-only terminal can be a prefabricated or temporary building. CTRs may be unloaded using airstairs; they do not require jetways.

- CTRs will be most economical if they are flown separately from a hub schedule, kept to rapid turnaround time, and have limited luggage allowance.

- CTRs have the same go-around space and missed approach requirements as turboprops.

- CTRs face the same separation requirements as turboprops in terms of air traffic control and wake vortex separation.

- On dedicated CTR-only runways, CTRs can land on a 9-degree glide slope, but on a mixed use runway (CTRs and turboprops) they must fly a more standard approach (e.g., 6 degrees).

- CTRs have the performance standard detailed in LMI’s technical report, *Civil Tiltrotor Feasibility Study for the New York and Washington Terminal Areas*:[3] top speed of 330 knots at 28,000 feet of altitude, efficient cruising speed of 300 knots, rotation of props at 1,000 feet from takeoff and landing points, total range of 600 statute miles, and 40-passenger capacity.

In most cases, there was more than one way to allow CTR operation at the airport. We used multiple ratings in those circumstances.

Construction Scale

Our ground examination consisted primarily of looking for runway space. A CTR needs minimal runway space: 1,000 feet in length or less. In our previous work, we also had considered the needs of CTR gates and terminal buildings.[4] We did not look for ground space for these structures in this study, for several reasons:

- Virtual gates and terminals can be created in a variety of places by using transport buses and temporary buildings.

- Gate use is a political topic at many airports. Ability to use a gate depends not on having geographical plots of land but on getting a hub airline’s consent to building gates. Estimating the likelihood or difficulty of that effort is outside the scope of this survey.

- CTRs may use existing terminal facilities as an integral part of hub-and-spoke operations.

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3 Logistics Management Institute, *Civil Tiltrotor Feasibility Study for the New York and Washington Terminal Areas*, Report NS904S2, Virginia Stouffer, Jesse Johnson, and Joana Gribko, February 2000.

4 Logistics Management Institute, *Terminal Civil Tiltrotor Feasibility*, Report NS904T1, Virginia Stouffer, Jesse Johnson, Joana Gribko, February 2000.

In examining airport surfaces, we looked for the following possible CTR runway sites:

- Unused or underused (and open) runways, such as turboprop runways
- Underused aprons, taxiways, and parking areas
- Unused land on airport property that is not likely to interfere with existing runway flows if a CTR runway were placed there, and is unlikely to increase the noise liability for nearby residential neighborhoods
- Unused land off airport property that is not likely to interfere with existing runway flows, and is unlikely to increase the noise level for nearby residential neighborhoods
- Sites at which vertical operations into the airport are the only possibility for independent operations
- Sites at which on-airport structures would have to be moved to create a CTR operations area.

UNDERUSED RUNWAYS

At a minimum, we can assume that CTRs can operate in place of jets, landing and departing on the same runways that jets use, although this solution is gap-filling at best. The CTR we envision carries fewer passengers than the average jet aircraft, so replacing a jet arrival with a CTR arrival is unlikely to be profitable; CTRs would be allowed to land only in the jets' nonpeak hours. This situation does not indicate large capacity increases from CTR use.

Given the trend of decreasing turboprop use in the United States, however, we looked for runways of less than 6,000 feet in length—"stub" runways—that will be underused or unused by the jet fleet. Finding an underused stub runway was an indication that CTRs could be incorporated into the airport's mix of operations fairly easily. Where stub runways have been closed because their use interferes with Instrument Landing System operation on a larger jet runway, we do not consider these closed runways usable.

UNDERUSED APRONS AND TAXIWAYS

If we could not locate a usable stub runway, we looked for out-of-the way aprons and taxiways that could be converted to CTR runways without disrupting the main runway flow. Sometimes a new CTR runway could be created only by staggering the CTR flow with the flow off the main runways.

Many of the airports we examined have only two runways, both jet length. In these cases, we looked for taxiways, aprons, parking spaces, and underused concrete surfaces to find a surface that would enable independent CTR operations.

UNDERUSED OFF-AIRPORT LAND

We also looked for vacant land adjacent to the airport. Some airports, such as Dulles International Airport, are surrounded by many acres of vacant land that can be developed for airport use as well as used as a buffer area for airport noise. Other airports, such as Atlanta's Hartsfield International Airport, are completely hemmed in by highways, businesses, and residential neighborhoods, and all on-airport property is occupied. In the case of Dulles, we determined that locating an independent CTR runway on airport property would be fairly easy, although we noted that it would be located some distance from the main terminal. Distance from the potential CTR runway to the main terminal was a consideration because airlines may choose to adopt CTRs as a hub feeder operation. In fact, our rating scheme captures the possibilities of unused land close to the existing main terminal and unused land as far away as 5 nautical miles (nm) from the existing main terminal.

RELOCATING STRUCTURES

When the airport's property and surrounding area was particularly well used, we considered the possibility of moving existing structures to make room for a CTR runway. For example, LaGuardia Airport has converted an employee parking lot to an apron for aircraft parking to increase the airport's capacity during poor weather. (A public parking lot was converted to an employee parking lot.) To our knowledge, the public parking lot was not moved, and the spaces were not replaced elsewhere, so this approach obviously can have negative impacts. Although we identified six instances in which existing structures could be moved to create space for a CTR runway, we explored this option only when other options were unavailable. For instance, we concluded that Atlanta Hartsfield has no room for CTRs unless the airport authority moves the fuel farms, which would be extremely expensive and is unlikely to be a viable alternative. Relocating cargo operations, fuel farms, and parking areas is not considered a minor change and would be undertaken only if it were the cheapest alternative for increasing capacity. We did not consider moving fuel farms to be a viable alternative for most airports because the cost of doing so is likely to outweigh the benefits gained from CTR capacity.

VERTICAL OPERATIONS

Except for mixing CTRs with jets, our least-preferred option was to open vertical CTR operations at an airport—such as on top of a terminal building. This option is least preferred because this approach burns the most fuel, is considered more dangerous by pilots in the event of an equipment failure, and because approaches to the tops of buildings often conflict with other structures and runway flows. Only Las Vegas rated this approach.

Capacity Scale

We rated each construction possibility for its potential for adding to capacity. We rated airports that had more than one option for each construction possibility. For example, one airport might have both unused land near the terminal and unused land 1–5 nm from the terminal.

This rating is meant to approximate the extent to which a capital improvement will enable additional operations at the airport. The type of capacity increase we anticipate is stated in terms of independent or dependent operations, which allows us to bound the upper and lower potential additional flights per hour according to dependent or independent flows at other airports. The true number of additional operations enabled, however, depends not only on the runway approach and departure flows and airspace constraints (which we did consider) but also on gate use, taxiway configuration, and new terminal buildings—which we did not consider. For example, a new independent, jet-length runway can enable up to 70 new operations per hour. In practice, however, mixing arrivals and departures on the runway cuts that number nearly in half; sharing resources such as taxiways with another major jet runway often means the maximum capacity of a new jet runway is 35-plus operations. If the runway is alternating operations with another major runway, the increase may be only 10 operations per hour (if that many). We offer these numbers not as standards for new runway studies; we offer them only as an example of how the increase in capacity from a new runway can vary, depending simply on airport runway layout. A simulation study provides a more detailed estimate of expected increases in operations.

Under FAA rules and procedures, separation between parallel runway centerlines must be at least 4,300 feet for independent operations in all weather conditions. If parallel runway centerlines are less than 4,300 feet apart, the runways are considered dependent under IFR, and aircraft on approach to the two runways must be staggered. If parallel runways are less than 2,500 feet apart, they must be treated as a single runway under IFR operations.

Our examination of the airports and potential new runways led us to an assessment according to one of the following capacity increment categories.

CTR operations enable:

- New simultaneous, parallel, noninterfering operations, completely independent of existing operations
- New staggered or intersecting operations (staggered or intersecting with one or more main jet runways)
- Simultaneous, parallel, noninterfering operations on a runway that also is used by turboprops

- Staggered or intersecting operations on a runway that also is used by turboprops
- Little to no capacity increase because the jet runway is the only available surface
- Unknown capacity increase.

New Simultaneous, Noninterfering Operations

Completely independent CTR operations are the best capacity improvement that can be hoped for. Such operations are feasible when a new runway can be built approximately one nautical mile from existing jet runways so that aircraft approaching the airport have simultaneous independent parallel approach paths, free from obstructions such as mountains or another runway or the airport's approach/ departure space. Land and airspace must be available. The general standard in the United States for simultaneous independent operations is 4,030 feet lateral separation, although the separation must be greater at high-altitude airports because aircraft performance is degraded in thinner air. An aircraft landing at Denver requires more lateral separation space because we cannot be assured that it can climb out and execute a missed approach with the same level of maneuverability as it could at sea level.

At very busy airports with extremely complex airspace, we judged that it was impossible to allocate simultaneous approach airspace without infringing on other airports' and runways' airspace. Two examples are O'Hare and Houston Hobby.

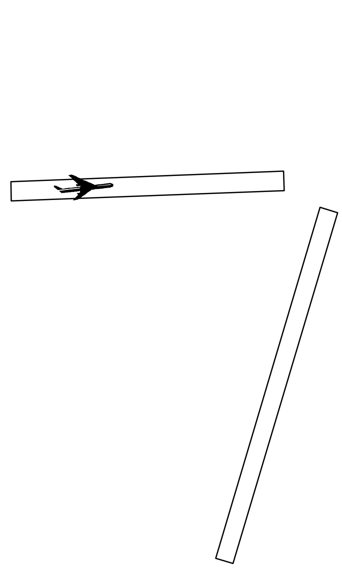
Land for a new runway must be unoccupied or not in a high-valued use. High-valued uses include shopping malls and dense suburban neighborhoods. We consider it highly unlikely that a shopping mall or suburban neighborhood would be moved to make room for a CTR runway. Non–high-valued uses include farms and abandoned industrial areas. The new runway must not abut residential neighborhoods that hitherto have not had to endure aircraft noise. In our study, we considered the possibility of planting a new runway near a suburban residential neighborhood unlikely in view of current resistance to aircraft noise.

New Dependent Operations

Dependent operations on a new CTR-based runway are the second-highest capacity-increasing possibility. Dependent operations would occur when the new runway has less than 4,030 feet of lateral separation or the CTR runway cannot be placed in a parallel orientation to the main runway, so that in some configuration the arrival or departure paths of the CTR runway and the main jet runway would intersect.

The term *dependent* or *staggered* operations merely refers to the fact that the approach or departure paths intersect at some point. In the case of a missed approach or aborted takeoff, an aircraft on one runway can overshoot and occupy the intersecting runway. For this reason, intersecting runways in the United States are conducted with staggered operations. Thus, if an overrun does occur, there is no aircraft on the intersecting runway, and no collision can happen. (See Figure 4-1 for an example of intersecting runways.)

Figure 4-1. Intersecting Runways



INDEPENDENT SHARED OPERATIONS

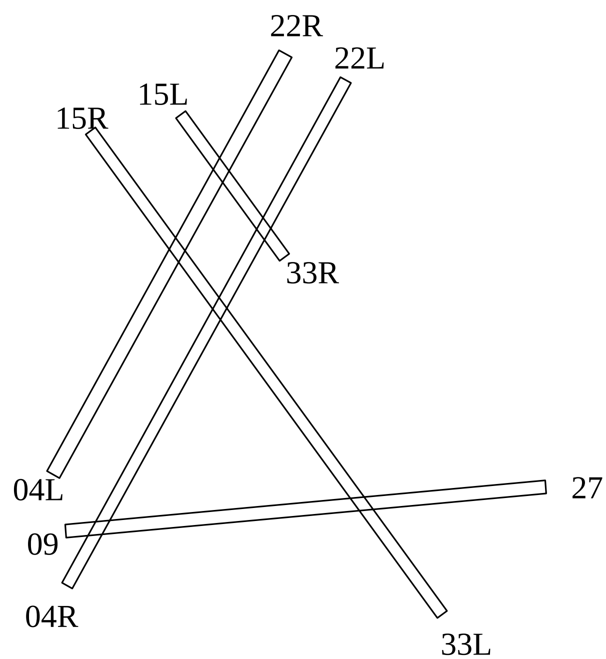
Independent shared operations are possible when the CTR can operate on an existing shorter runway that already is situated an appropriate distance from the main runway, so that independent operations are enabled, although the runway is in use by turboprop aircraft. Although regional jets are quickly replacing turboprops, such transitions and the elimination of an entire fleet do not happen quickly. Turboprops are likely to be a part of U.S. airspace operations for many years to come, and it is likely that CTRs would have to share runways with turboprops. The difference between this option and the new independent runway option is that a totally new runway offers a greater increment of additional flights to capacity than gap-filling on an underutilized runway, assuming that demand is present.

DEPENDENT SHARED OPERATIONS

Dependent shared operations refer to CTRs that use an existing stub or turboprop runway in an intersecting configuration with the main jet runway. Boston's runway 15L/33R is a good example (see Figure 4-2). Runway 15L/33R, which is only 2,557 feet long, is less than 2,000 feet from runway 15R/33L—a 10,000-foot jet runway. Runway 15L/33R operations must stagger with those of runway 15R/33L; essentially, aircraft that are arriving at or leaving 15L/33R have to try to fit into holes in the flow of jet operations on the parallel runway. Runway 15L/33R crosses runways 04R/22L and 04L/22R. The extended centerline of

15L/33R crosses the extended centerline of the third jet runway at Logan, 09/27. Operations on 15L/33R would have to be staggered with those on 15R/33L and 09/27. Presumably, the 15/33 pair are closed when the 04/22 pair are in operation because of unfavorable winds; in that configuration, use of 15L/33R by CTRs is not possible.

Figure 4-2. Boston's Runways



MIX WITH JETS

Where there are no stub runways to use; no out-of-the-way taxiways, parking spaces, or aprons; and the land around the airport is densely used, sometimes there is no dedicated spot to put new CTR operations. If CTRs were to operate into such an airport, they would have to use the main runways. Although it may be desirable for CTRs to enter a busy hub airport and feed hub-and-spoke operations, the smaller capacity of the CTR makes it an unlikely candidate for large-scale replacement of jets at busy airports; moreover, replacement of jets by CTRs does not increase enplanements. An airline would pursue this strategy only if the profitability of the CTR feeder operation were very high.

UNKNOWN

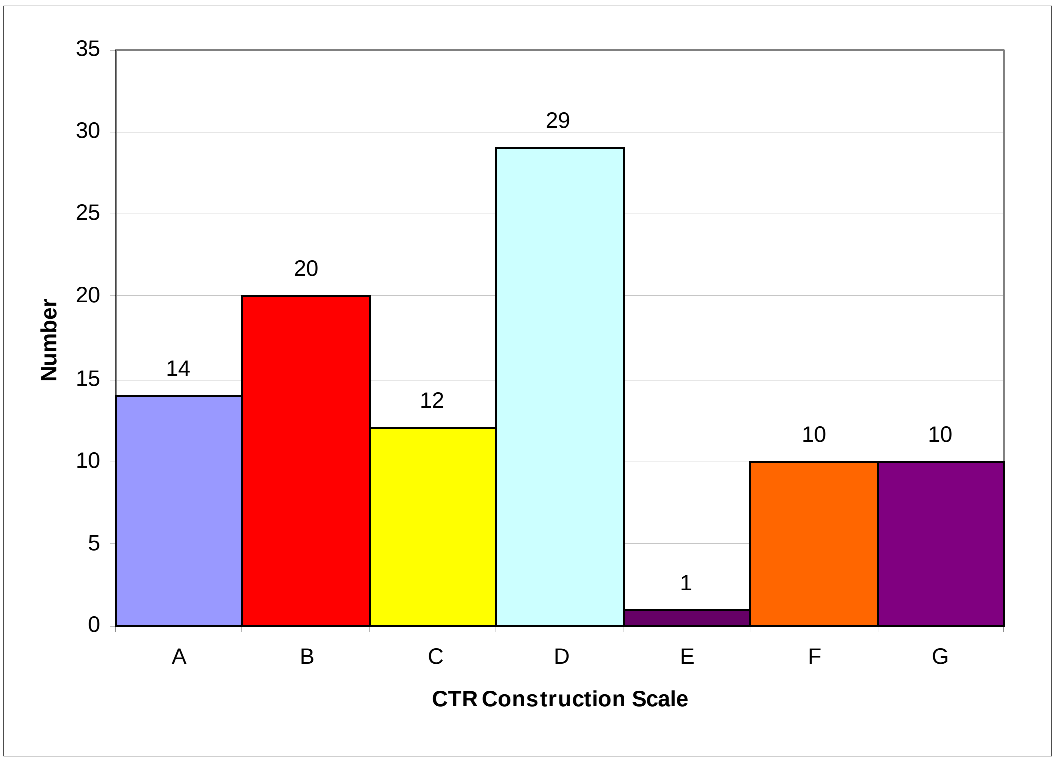
We created the "unknown capacity increase" category to capture capacity increases whose effect we could not assess with any certainty.

RESULTS

Construction Scale Ratings

We immediately removed Teterboro from the analysis because of its lack of scheduled operations. We rated the remaining 63 LMINET airports according to the construction and capacity scales described above. As we have noted, some of the airports presented more than one construction possibility for CTR operations; these airports received multiple ratings. Double-counting all of the construction possibilities yielded the results depicted in Figure 4-3.

Figure 4-3. CTR Operation Construction Ratings at 63 Airports (With Double-Counting)

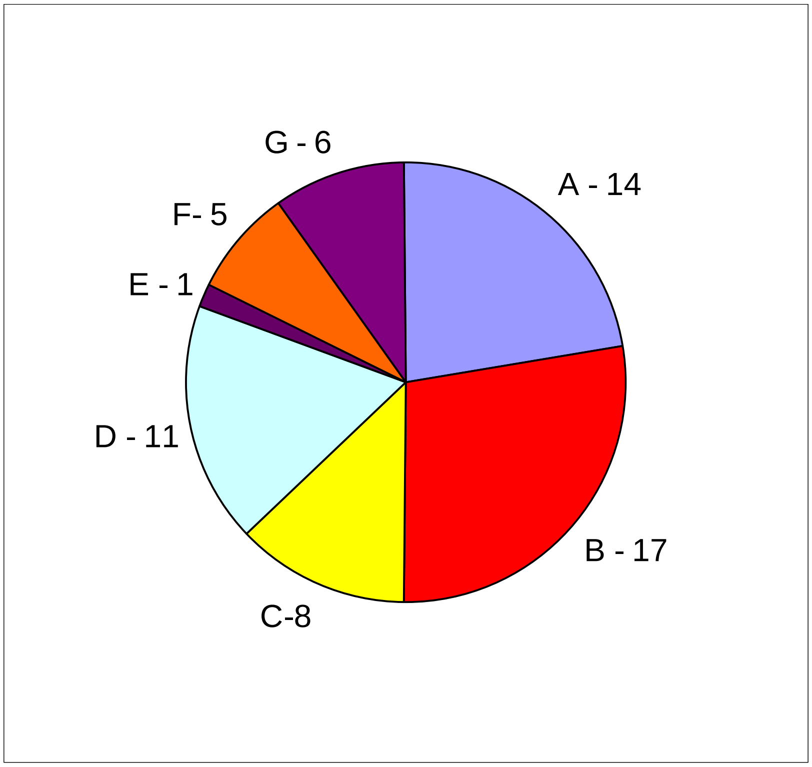


As Figure 4-3 shows, only one of the airports received an E rating—the construction category that corresponds to vertical-only operations. Vertical-only operations present such a cost barrier that we considered them only if glide-slope type approaches and departures were impossible; often they were prohibited by dense usage of the airport surface and dense population surrounding the airport. Ten airports received the G rating, which indicates that CTRs operating at this airport would have to join the mix on the main jet runways.

Fourteen airports received an "A" rating, and 20 airports received a B rating—both of which indicate that existing concrete (e.g., apron or stub runway) on the airport surface could be used to create a space for CTR operations. A and B ratings can indicate a low-cost increment to adding CTR operations at an airport.

B (can use existing stub runway) and D (CTR-only runway construction possible on unused land 1–5 nmi from terminal) were the ratings with the highest frequency of occurrence; in fact, 12 airports received both B and D ratings. To help illuminate the airports' construction ratings distribution, Figure 4-4 shows the airport ratings without double-counting. We counted each airport's ratings only once; in addition, we counted only the highest rating—arbitrarily assuming that an A rating is better than all others and that a B is better than C, D, E, F, and G, and so on.

Figure 4-4. CTR Operation Construction Ratings Without Double-Counting



In Figure 4-4, ratings B and A occur with the greatest frequency. Together, A and B fit half the airports surveyed. Rating D—a new runway far from the main terminal—also is also common. Fewer than a quarter of the airports received the high-cost option, F (move existing structures to create CTR runway) and the mix with jets option (G).

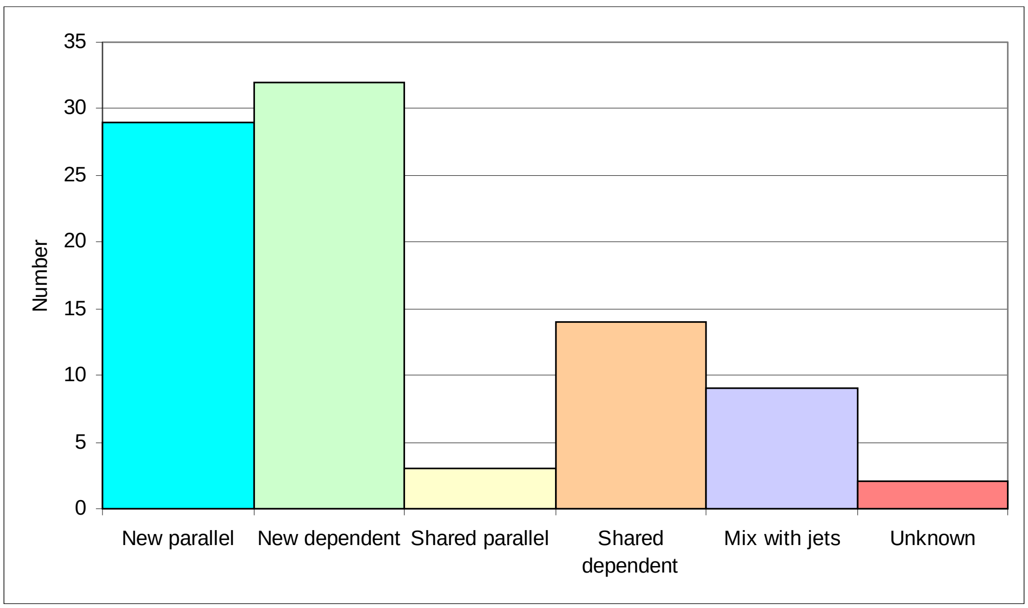
Capacity Scale Rating

Six ratings were possible in assessing the potential improvement in capacity resulting from each construction option. The first two deal with entirely new runways that are solely for CTR use, whether independent of the main runway or not. The second pair of ratings assess the shared use of a stub runway, independent or dependent of the main runway. If turboprops disappear from the U.S. fleet mix, options 3 and 4 become the same as ratings 1 and 2, except that in terms of cost options 1 and 2 require new construction.

The final two ratings encompass an inability to separate CTRs from the rest of the fleet (rating 5) and an inability to judge whether CTRs could add capacity at all, usually influenced by other factors (rating 6.)

The relative frequency of each rating is shown in Figure 4-5.

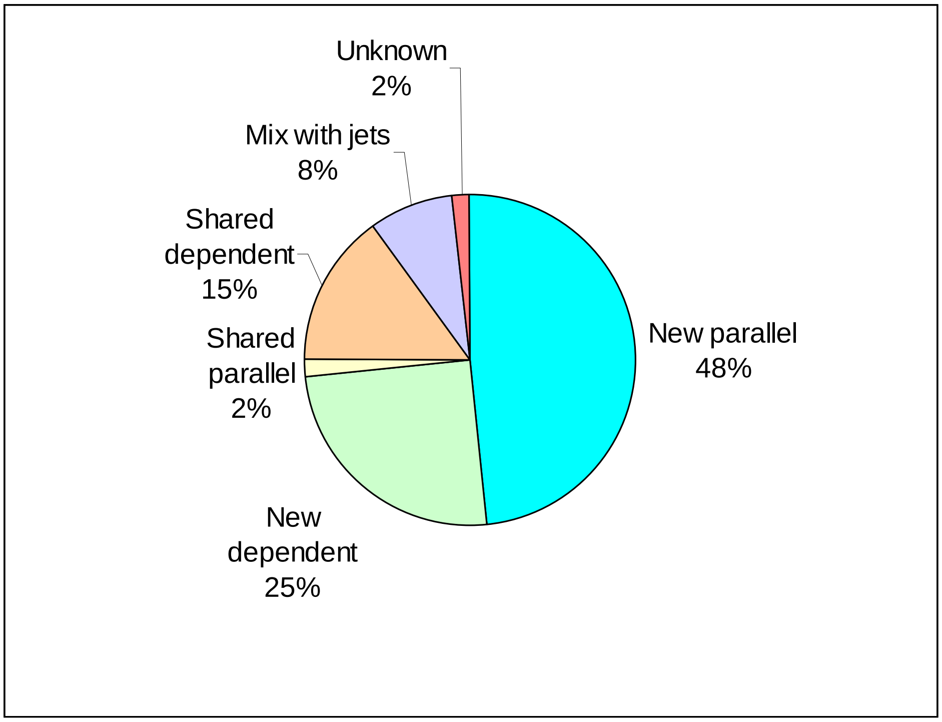
Figure 4-5. CTR Operation Capacity Increases Possible (With Double-Counting)



As Figure 4-5 shows, for many airports there is space for an entirely new CTR runway. Many of the 63 airports we examined would not have room for a new jet runway, but a CTR runway takes far less space than a conventional runway. Nineteen of the airports we surveyed—about one-third of our sample—had an existing stub runway that could be converted to a CTR runway.

Following the same methodology as we used for the construction scale, Figure 4-6 presents the capacity increases that are possible if only the highest rating is counted for each airport.

Figure 4-6. CTR Operation Capacity Ratings Without Double-Counting



In Figure 4-6, a whopping 48 percent—nearly half—of the airports we considered have space for a new parallel, independent CTR runway. The number of airports with available stub runways for CTR operation dropped, probably because many of these airports also had room for a new CTR runway and in our calculus, we counted only the highest-valued rating.

Combined Results

Forty-nine airports (78 percent of the sample) had a rating of A through D on the construction scale—corresponding to either existing concrete surfaces or open land for use—and a rating of 1 through 4 on the capacity scale, indicating either independent or staggered operations on that new CTR runway. Thirty airports, or nearly half, were rated for a new independent CTR runway (shared and unshared). These figures indicate that the busiest airports in the United States generally have room for additional operations if CTRs are added to U.S. fleets. Additional operations create additional capacity.

On the other hand, seven airports received ratings indicating that CTRs would not be able to add capacity to those airports—that CTRs would be forced to share the main runways. Those airports are the following:

- San Jose
- Fort Lauderdale

- Islip
- Las Vegas McCarran International
- Memphis International
- Santa Ana
- Tampa International.

The data we used for reaching these conclusions are reproduced in Appendix C, and listed in References.

COSTS OF AIRPORT CHANGES

We undertook a brief survey of airport construction costs to offer some rough order-of-magnitude estimates or bounds on the costs of adding CTR runways at the candidate airports. We researched articles on airport construction, airport planning studies, newspaper articles, DoD construction cost factors, and the FAA's Airport Capacity Enhancement Plan CD-ROM. We only kept data that listed both the physical dimension of the construction project and the cost. We inflated all costs to year 2000 dollars by using the Gross Domestic Product inflator, which is available from the Council of Economic Advisors.

Table 4-3 shows the cost ranges we discovered for building new runways, converting runways, and building runway extensions. Costs shown are depicted in per-foot increment of the relevant runway. General aviation (GA) runways are 75 feet across; costs shown for constructing a GA runway are average costs of building each foot of a 75-foot wide runway. Air carrier runways are held to 150 feet wide. The cost of upgrading a GA runway to an air carrier runway includes widening the runway by 100 percent.

Table 4-3. Cost of New Airport Runways, Per Foot of Length

	GA runway	Off-airport runway construction that requires moving highways or power lines, razing neighborhoods, or building over water	Converting taxiway or GA runway to a jet runway	On-airport new runway	Off-airport new runway	On-airport runway extension	Off-airport runway extension
Average	$5,636	$46,212	$7,442	$7,623	$18,874	$8,656	$33,376
Min	857	1,010	99	578	5,409	791	1,010
Max	13,687	245,093	15,428	32,419	51,748	33,933	124,036
Count	3	19	6	30	22	20	12

We expected the cost of constructing runways on land that does not yet belong to the airport to have the highest cost. If the calculation includes the cost of land acquisition, this is true because the cost of land acquisition (which is not included in these figures) often equals the cost of the runway—approximately $75–100 million. Once the cost of land acquisition is excluded, however, for most airports the cost of constructing runways away from the existing air traffic actually is slightly cheaper. This finding is not evident in Table 4-3, however, because of the presence of several metropolitan airports (MSP, MSY, PHL, and SEA in particular) that plan expansions by buying adjoining land and have increased the average cost of off-airport new runways. In some cases, studies noted that it would be necessary to move roads, rail lines, or power lines to proceed and gave cost estimates for that work.

The figures in Table 4-3 are based on estimates of airport construction projects; they are not based on actual construction costs.

We found that the cost of building new terminals is higher than the cost of building new runways. Some representative costs for building taxiways, terminals, and aprons are listed in Table 4-4.

Table 4-4. Costs for Airport Construction

Average airport costs	$ (millions)
Airline gate	1.1
Adding an ILS to a runway	1.0
Terminal	600.0
Taxiway	9.0
Constructing a taxiway, per foot	820.0
Adding an apron or holding area	8.5

Using the foregoing information, we can provide some cost averages and ranges for the construction scale given for CTRs earlier in this chapter (Table 4-5). These figures are gross figures, based on estimates of future construction; they are not in any way airport specific. As above, these costs ignore the cost of land acquisition for off-airport land, which often is equal to the construction cost.[5] These estimates assume that a CTR would require air carrier-quality runways. Additional costs for terminals, gates, and taxiways apply, depending on airport configuration.

Table 4-5. CTR Runway Construction Cost Ranges

Code	Description	Average	Min	Max
A	Can use existing aprons/taxiways for CTR runway	$7,442,000	$99,000	$15,428,000
B	Can use existing stub runway for CTR runway	0	0	0

[5] Even where the construction is entirely on-airport, sometimes it is necessary for the airport to purchase adjoining land to ensure an adequate buffer zone, for safety, noise and backwash.

Table 4-5. CTR Runway Construction Cost Ranges (Continued)

Code	Description	Average	Min	Max
C	CTR runway possible on unused land near terminal	7,623,000	578,000	32,419,000
D	CTR runway possible on unused land 1–5 nmi from terminal	18,874,000	5,409,000	51,748,000
E	Vertical ops the only possibility	unknown	unknown	unknown
F	Must move existing structures to create CTR runway	46,212,000	1,010,000	245,093,000
G	No space for new runway; must mix with jets	0	0	0

The figures in Table 4-5 for CTR runways are much lower than the average cost of a full airline runway. Given the potential capacity improvements, at some airports the benefits of an additional independent traffic stream may outweigh the costs by a larger margin than a comparable addition of a major runway.

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Appendix A
Glossary of Airport Identifiers

ABQ	Albuquerque International Airport, Albuquerque, New Mexico
ATL	The William B. Hartsfield Atlanta International Airport, Atlanta, Georgia
AUS	The Robert Mueller Municipal Airport, Austin, Texas
BDL	Bradley Locks, Bradley Locks, Mass.
BNA	Nashville Metropolitan Airport, Nashville, Tennessee
BOS	General Edward Lawrence Logan International Airport, Boston, Massachusetts
BUR	Burbank-Glendale Airport, Burbank, California
BWI	Baltimore-Washington International Airport, Baltimore, Maryland
CLE	Hopkins International Airport, Cleveland, Ohio
CLT	Douglas Airport, Charlotte, North Carolina
CMH	Columbus International Airport, Columbus, Ohio
CVG	Cincinnati-Northern Kentucky Airport, Cincinnati, Ohio
DAL	Love Field, Dallas/Fort Worth, Texas
DAY	Dayton International Airport, Dayton, Ohio
DCA	Washington National Airport, Washington, D.C.
DEN	Denver International Airport, Denver, Colorado
DFW	Dallas-Fort Worth International Airport, Dallas/Fort Worth, Texas
DTW	Detroit Metropolitan Wayne County Airport, Detroit, Michigan
ELP	El Paso International Airport, El Paso, Texas
EWR	Newark International Airport, Newark, New Jersey
FLL	Ft Lauderdale-Hollywood International, Ft. Lauderdale, Florida

GSO	Greensboro-High Point Airport, Greensboro, North Carolina
HOU	William P. Hobby Airport, Houston, Texas
HPN	Westchester County Airport, Westchester County, NY
IAD	Dulles International Airport, Washington, D.C.
IAH	Houston Intercontinental Airport, Houston, Texas
IND	Indianapolis International Airport, Indianapolis, Indiana
ISP	MacArthur Field, Long Island, New York
JFK	John F. Kennedy International Airport, New York, New York
LAS	McCarran International Airport, Las Vegas, Nevada
LAX	Los Angeles International Airport, Los Angeles, California
LGA	La Guardia Airport, New York, New York
LGB	Daugherty Field, Long Beach, California
MCI	Kansas City International Airport, Kansas City, Missouri
MCO	Orlando International Airport, Orlando, Florida
MDW	Midway Airport, Chicago, Illinois
MEM	Memphis International Airport, Memphis, Tennessee
MIA	Miami International Airport, Miami, Florida
MKE	General Mitchell Field, Milwaukee, Wisconsin
MSP	Minneapolis-Saint Paul International Airport, Minneapolis-Saint Paul, Minnesota
MSY	New Orleans International Airport, New Orleans, Louisiana
OAK	Oakland International Airport, Oakland, California
ONT	Ontario International Airport, Ontario, California
ORD	Chicago O' Hare International Airport, Chicago, Illinois
PBI	Palm Beach International Airport, Palm Beach, Florida
PDX	Portland International Airport, Portland, Oregon

PHL	Philadelphia International Airport, Philadelphia, Pennsylvania
PHX	Phoenix Sky Harbor International Airport, Phoenix, Arizona
PIT	Pittsburgh International Airport, Pittsburgh, Pennsylvania
RDU	Raleigh-Durhum Airpert, Raleigh, North Carolina
RNO	Reno Cannon International Airport, Reno, Nevada
SAN	Lindbergh Field, San Diego, California
SAT	San Antonio International Airport, San Antonio, Texas
SDF	Standiford Field, Louisville, Kentucky
SEA	Seattle-Tacoma International Airport, Seattle, Washington
SFO	San Francisco International Airport, San Francisco, California
SJC	San Jose International Airport, San Jose, California
SLC	Salt Lake City International Airport, Salt Lake City, Utah
SMF	Sacramento Metropolitan Airport, Sacramento, California
SNA	John Wayne Airport, Orange County, California
STL	Lambert Field, Saint Louis, Missouri
SYR	Hancock Field, Syracuse, New York
TEB	Teterboro Airport, Teterboro, New Jersey
TPA	Tampa/St. Petersburg Airport, Tampa, Florida

Appendix B
Calculation of the Learning Curve

The calculation of the learning curve is important because it is the key portion of the demand equation.

The data given in the CTRDAC Study[1] consists solely of

- selling price per aircraft
- break-even number of aircraft
- development costs
- learning curve parameters.

By definition, the total revenues at break-even are equal to the selling price per aircraft multiplied by the number of aircraft sold. Total costs at break-even are equal to the sum of the total development and manufacturing costs, or the sum of fixed costs and variable costs. The development costs are given; when they are subtracted from the total revenues, what is left are total variable costs. Dividing this amount by the number of aircraft gives the average variable cost per aircraft.

Two learning curve parameters are given: before and after break-even. The maximum cost prediction occurs when the break-even aircraft has the average variable cost (AVC). This is the upper limit; because the marginal costs are not known, however, this is the only method for calculation. Thus, we have one data point: at 506 aircraft, the AVC is $18.2 million. Next, the learning curve data are used to predict two additional cost data points. Learning curves mean that when the quantity produced doubles, the unit cost is reduced to *X* percent. This production line had an 85 percent before break-even and a 90 percent learning curve after break-even. Therefore, when the 506 aircraft are doubled to 1,012 aircraft, the AVC is cut by 10 percent. Similarly, when the 1,012 aircraft are doubled to 2,024, the AVC is cut by another 10 percent. The same method is followed to generate AVCs for 253 and 126.5 aircraft. Here, however, the costs actually increase, as we are moving in the opposite direction toward lower quantities. This method produces the five data points shown in Table B-1.

[1] U.S. Department of Transportation, "Civil Tiltrotor Development Advisory Committee," December, 1995.

Table B-1. Theoretical Lot Costs

Aircraft number	Average variable cost
126.5	$25,235,522
253.0	21,450,194
506.0	18,232,665
1012.0	16,409,399
2024.0	14,768,459

A nonlinear regression is performed on these five points to generate the AVC curve. It is of the form

$$AVC(\text{aircraft}) = \exp[\{ln(\text{aircraft})* -.17674\} + 17.84208]$$

and has an R-squared value of 0.993533. The summary data are shown in Table B-2.

Table B-2. Average Variable Cost Profile

Aircraft number	Average variable cost
100	$24,844,621
200	21,980,006
300	20,459,977
400	19,445,685
500	18,693,697
600	18,100,917
700	17,614,417
800	17,203,574
900	16,849,146
1000	16,538,291
1100	16,262,032
1200	16,013,859
1300	15,788,908
1400	15,583,454
1500	15,394,584
1600	15,219,981
1700	15,057,771
1800	14,906,419
1900	14,764,653
2000	14,631,406

Appendix C

Airport Data and Layouts

	code	airport	city	state	List Runways	Runway lengths (ft)	CTR use existing rwy/twy	Space for CTR rwy?	Construction Scale	Capacity Scale
1	ATL	William B. Hartsfield International	Atlanta	GA	09R/27L, 09L/27R, 08R/26L, 08L/26R	9000, 11889, 10000, 9000	jet rwys	no, unless move north cargo area or fuel farm	F/G	F2 G5
2	BOS	General Edward Lawrence Logan International	Boston	MA	15R/33L, 15L/33R, 22R/04L, 22L/04R, 09/27	10081, 2557, 7860, 10005, 7000	heliport near SWA terminal. Prop rwy 15L/33R	possibly - heliports in proximity	B/D	B4 D6
3	BWI		Baltimore	MD	15R/33L, 15L/33R, 10/28, 22/04	9519, 5000, 10502, 6005	prop rwy; police heliport in SE corner of apt	yes	C	C1
4	DCA	Ronald Reagan National	Washington	VA	36/18, 03/21, 33,15	6869, 5189, 4905	03 and 33	no	B	B4
5	DEN	Denver International	Denver	CO	16/34, 17L/35R, 17R/35L, 07/25, 08/26	12000, 12000, 12000, 12000, 12000	use twy EC in EW config. Use jet rwys in N/W config.	yes, parallel	C	C1
6	DFW	Dallas Ft Worth	Ft Worth	TX	13R/31L, 13L/31R, 17R/35L, 17C/35C, 17L/35R, 18R/36L, 18L/36R	9500, 9000, 13401, 11388, 8500, 11388, 11388	prop rwy (13L/35R) is an obvs candidate	yes, parallel to 13R/31L (s)	B/ D	B4 D2
7	EWR		Newark	NJ	11/29, 04R/22L, 04L/22R	6800, 9980, 10000	stub rwy 11/29	yes, on pier	B/ D	B4 D2
8	HPN	White Plains / Westchester County	White Plains	NY	16/24, 11/29	6548, 4451	stub rwy 11/29, 4450 ft	if close 11/29, room for a short rwy parallel to 16/24, 2500 ft away	B/ D	B4 D2
9	IAD	Dulles	Dulles	VA	01R/19L, 01L/19R, 11/26	11500, 11500, 10500	mix w/ props	yes, on apron at end of 11/26: parallel to main rwys	A/G	A1, G5
10	IAH	George Bush International	Houston	TX	15L/33R, 15R/33L, 08/26, 09/27	12001, 6038, 9401, 9999	6000-ft stub?	yes, several jet rwys planned	BCD	B4 C1 D1

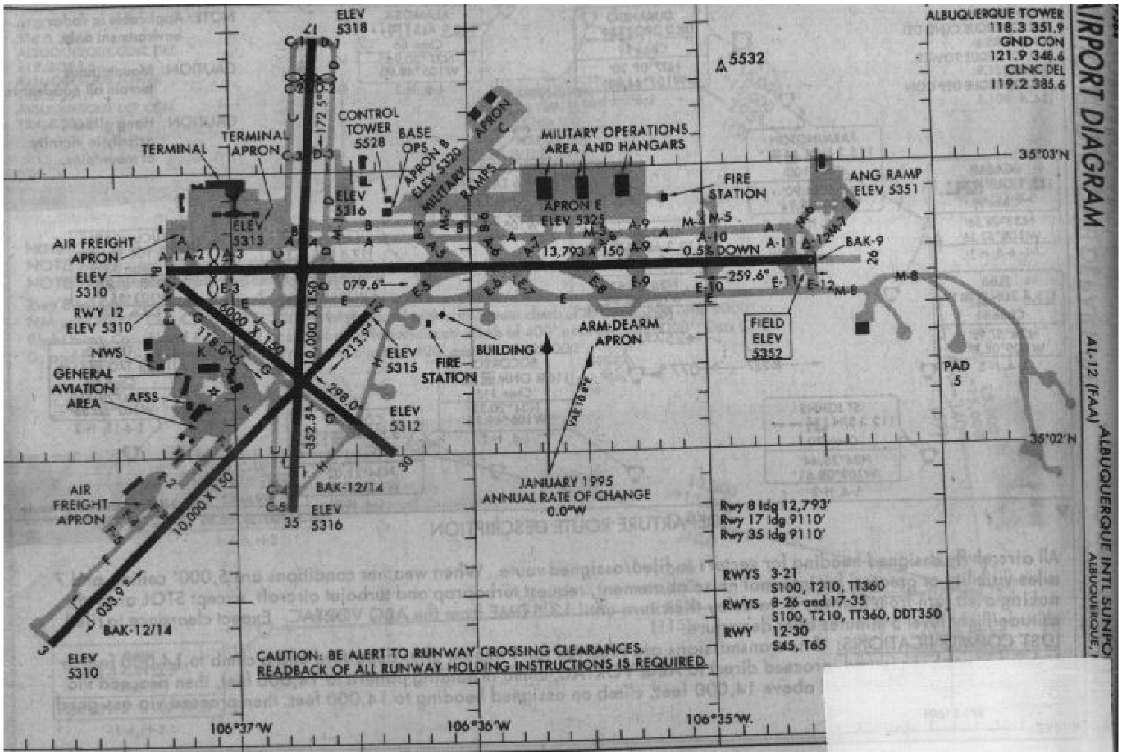
	code	airport	city	state	List Runways	Runway lengths (ft)	CTR use existing rwy/twy	Space for CTR rwy?	Construction Scale	Capacity Scale
11	JFK	John F Kennedy International	New York	NY	13R/31L, 13L/31R, 22R/4L, 22L/4R	14572, 10000, 11351, 8400	no / mix with jets	Yes, twys R (north end, nr cargo) and H (so. end). R would require paving, possibly moving a hangar, but both would enable CTR rwys short of terminal	F(twyR), A (twyH)	F(twyR), A (twyH); 3500 ft parallel separation
12	LAX		Los Angeles	CA	06R/24L, 06L/24R, 7L/25R, 7R/25L	8925, 10285, 12091, 11096	no / mix with jets	Possibly in middle of airport - but not enough separation for parallel operations	F/G	F1, G5; move El Segundo neighborhd for new rwy
13	LGA	Laguardia	New York	NY	22/04, 13/31	7000, 7000	no	Yes, if use Flushing apt… Ten tank farm nearby.	F	F1/2
14	LGB	Long Beach	Long Beach	CA	12/30, 07L/25R, 07R/25L, 34L/16R, 34R/16L	10000, 6192, 5420, 4470, 4267	yes - 4000'	no		B4
15	MCO	Orlando International	Orlando	FL	36R/18L, 36L/18R, 35/17	12005, 12004, 10000	no	yes, and fourth rwy planned	D	D 1/2
16	MDW	Midway	Chicago	IL	13L/31R, 13C/31C, 13R/31L, 04L/22R, 04R/22L	3859, 6522, 5142, 5509, 6449	yes	no	n/a	n/a
17	MSP	Minneapolis-St. Paul Wold Chamberlain	Minneapolis	MN	22/04, 30R/12L, 30L/12R	11006, 8002, 10000	YES; 22/04 IS UNUSED	yes; 3 rwys planned	C,D	C2 D2
18	ORD	O'Hare	Chicago	IL	14L/32R, 14R/32L, 09R/27L, 09L/27R, 04R/22L, 04L/22R, 18/36	13000, 10003, 10141, 7967, 8071, 7500, 5341	mix with props	apparently, to West and South	D6	Airspace the limiting factor
19	SAN	Lindbergh	San Diego	CA	09/27,	9400	mix	twy D / air cargo/corporate ramp	A	A2
20	SAT		San Antonio	TX	12L/30R, 12R/30L, 21/03	5518, 8502, 7505	12L not considered "A/C length" by SAT/ rwy 21/03 seldom used	2 new parallels rwys considered for N; CTR rwy pos also	D, B	B, D=1/2; "Relocate 25% of non AC ops ~ $11.25M benefit in ACE"
21	SEA		Seattle	WA	16L/34R, 16R/34L	11900, 9425	possibly north apron	possibly north apron; long taxi from terminal	A	A2

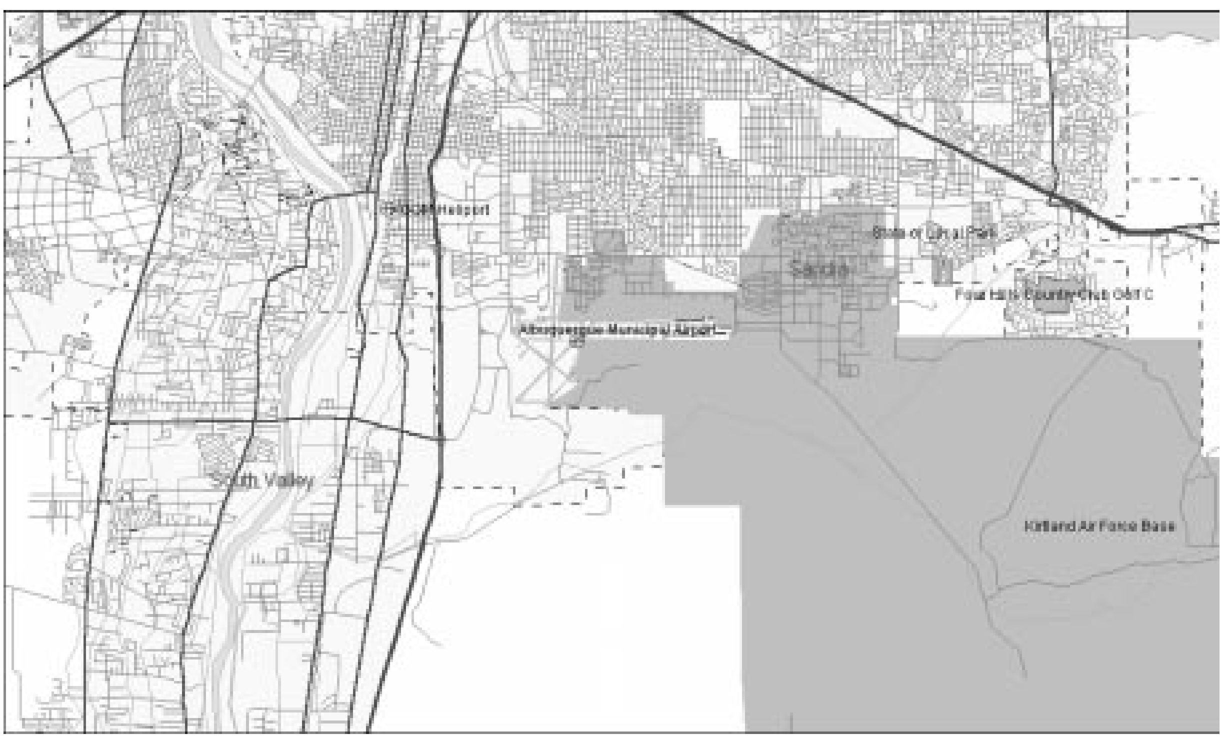
	code	airport	city	state	List Runways	Runway lengths (ft)	CTR use existing rwy/twy	Space for CTR rwy?	Construction Scale	Capacity Scale
26	BDL	Bradley International	Windsor Locks	MA	24/06, 33/15, 19/01	9502, 6846, 5145	too busy; 641680 pax/mo; 206 flts/day;12 flights per hour for 18 hrs	Yes, military installation next door		F1
27	BNA	Nashville International	Nashville	TN	02R/20L, 02C/20C, 02L/20R, 31/13	8000, 8000, 7702, 8500	if I'm correct - no / mwj; if ACE is correct, there's an unused rwy	no	no / B	no / B4
28	BUR		Burbank	CA	13/31, 08/26	6886, 6032		yes	D	D2
29	CLE	Hopkins International	Cleveland	OH	05R/23L, 05L/23R, 18/36, 10/28	8999, 7095, 6415, 6015	18/36 not getting used	yes, new jet rwy pos. 5/23 3500 ft to E	B/ D	B4 D2
30	CLT	Douglas International	Charlotte	NC	05/23, 18L/36R, 18R/36L	7501, 8676, 10000	05/23 used in VFR only	yes, to E and W	C D	C2 D1
31	CMH	Port Columbus International	Columbus	OH	28R/10L, 28L/10R	8000, 10250	CLOSED rwy 04/22(?)	to N and S	D B	D1 B2
32	CVG	Cincinnati	Covington	KY	18R/36L, 18L/36R, 09/27	11000, 10000, 10000	no/mix	to south, if planned dev does not occur; further south if it does		C 12 if not planned dev; D 1 if dev
33	DAL	Love	Dallas	TX	13L/31R, 13R/31L, 18/36	7753, 8800, 6149	18/36 unused	not needed	A	A4
34	DAY	James M. Cox Dayton International	Dayton	OH	24R/06L, 24L/06R, 18/36	10901, 8500, 7000	no	yes, to N	D	D1,2
35	DTW	Detroit Metropolitan Wayne County	Detroit	MI	21R/03L, 21C/03C, 21L/03R, 09L/27R, 09R/27L, (04/22 w'most)	12001, 8500, 10000, 8700, 8500	27/09 pair	not needed	A	A4
36	ELP		El Paso	TX	04/22, 08R/26L, 08L/26R	11010, 8025, 5493	08L/26R is prob'ly underutilized	yes; AFB, open space on apt, & on twy A	A B C D	A2 B3 C2 D1
37	FLL	Hollywood	Ft Lauderdale	FL	09L/27R, 09R/27L, 13/31	9000, 5776, 6930	13/31 underused	no	n/a	n/a
38	GSO	Friendship	Greensboro	NC	32/14, 05/23	6380, 10000	twy M, 300 ft from main rwy	yes	A F	A2 F1

	code	airport	city	state	List Runways	Runway lengths (ft)	CTR use existing rwy/twy	Space for CTR rwy?	Construction Scale	Capacity Scale
41	ISP		Islip	NY	24/06, 15R/33L, 15L/33R, 10/28	7002, 5186, 3212, 5036	mix with props	no	use existing	n/a
42	LAS		Las Vegas	NV	01L/19R, 01R/19L, 07R/25L, 07L/25R	9777, 9770, 10252, 14505	Props use the 01/19 pair. Mtns to west probably a problem for props and slow jets	Props use the 01/19 pair. Mtns to west probably a problem for props and slow jets	E	n/a
43	MCI		Kansas City	MO	19R/01L, 19L,01R, 09/27	10801, 9500, 9500	all rwys are jet length	yes	C	1
44	MEM	Memphis International	Memphis	TN	18R/36L, 18C/36C, 18L/36R, 09/27	9319, 8400, 9000, 8936	all rwys are jet lngth	no; several closed rwys that are now ILS non mvmt zones	n/a	n/a
45	MIA	Miami International	Miami	FL	09R/27L, 09L/27R, 12/30	10506, 13000, 9354	all rwys are jet lngth	signature FBO/ other nearby heliports	F	2
46	MKE	General Mitchell International	Milwaukee	WI	19R/01L, 19L/01R, 07R/25L, 07L/25R, 13/31	9690, 4182, 8011, 4800, 5868	19L used by props only now	green space (may be protected), warehouses around	D, F	D 1,2; F 1,2
47	MSY	Moisant	New Orleans	LA	10/28, 01/19, 06/24	10080, 7000, 3574	06/24 short	no	B, D (floating rwy?)	B2, D/F1
48	OAK		Oakland	CA	11/29, 09R/27L, 09L/27R, 15/33	10000, 6212, 5453, 3366	33/15 or apron at end of 29 and W	no, unless build into ocean	A	4,5
49	ONT		Ontario	CA	08L/26R, 08R/26L	12200, 10200	no / mix	no, unless noise level is low - pos. space near shopping ctr	D	2
50	PBI	Palm Beach International	West Palm Beacl	FL	09L/27R, 09R/27L, 13/31	7989, 3212, 6931	09R stub	east of 09R?	B C	B4 (GA)
51	PDX	Portland International	Portland	OR	10R/28L, 10L/28R, 03/21	11000, 8000, 7000	all jet length	yes	D	1,2
52	PHL	International	Philadelphia	PA	09R/27L, 09L/27R, 08/26, 17/35	10500, 9500, 5000, 5459	08 and 17	industrial area surrounding	A; twy E1/D1 at end of rwy 17	A1, B4, F2
53	PHX	Sky Harbor	Phoenix	AZ	08R/26L, 08L/26R	10300, 11000	no	yes; to s, n (NASA rpt indicates rwy to so. Was planned for 1999)	D	1,2
54	PIT	International	Pittsburgh	PA	10L/28R, 10C/28C, 10R/28L, 14/22	10502, 9708, 11500, 8101	yes; 8101 ft 14/22	yes	C	1

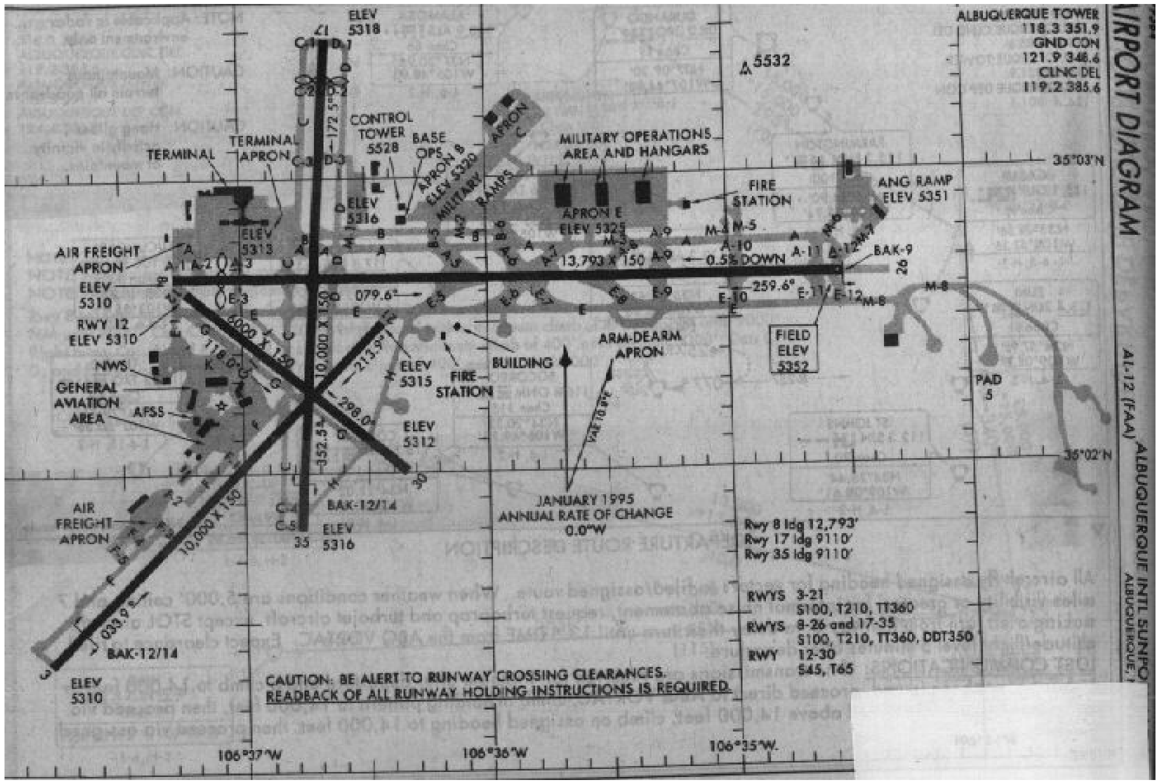
	code	airport	city	state	List Runways	Runway lengths (ft)	CTR use existing rwy/twy	Space for CTR rwy?	Construction Scale	Capacity Scale
55	RDU		Raleigh Durham	NC	05L/23R, 05R/23L, 14/32	10000, 7500, 3569	yes	yes; park	B, D	B2 D1
56	RNO		Reno	NV	16R/34L, 16L/34R, 07/25	11000, 9000, 6101	no	yes, to E	D	D12, dep on mtns
57	SDF	Standiford Field	Louisville	KY	17R/35L, 17L/35R, 11/29	10000, 8580, 7249	twy N a closed rwy? / probly no capac with UPS ops	no	A	A2 (probably not in IFR)
58	SLC		Salt Lake City	UT	16R/34L, 16L/34R, 17/35, 14/32	12000, 12004, 9596, 4892	14/32; clearly a closed rwy to E of 16L/34R, closed for ILS reasons	space to N; jet rwy considered there; mtns to east	D	1
59	SMF	Metropolitan	Sacramento	CA	16R/34L, 16L/34R	8600, 8600	no	yes	C,D	2
60	SNA		Santa Ana	CA	19R/01L, 19L/01R	5700, 2887	not recommended; GA rwy	no (greenway to s. is probly protected)	n/a	n/a
61	STL	Lambert-St Louis International	St Louis	MO	12R/30L, 12L/30R, 13/31, 06/24, 17/35	11019, 9000, 6290, 7602, 2878	31 and 17	no	B	4
62	SYR	Hancock	Syracuse	NY	28/10, 15/33	9003, 7500	a closed rwy; s. twy	yes	A, B	2
63	TPA	Tampa International	Tampa	FL	36L/18R, 36R/18L, 09/27	11000, 8300, 6998	no	no	n/a	n/a

ALBUQUERQUE

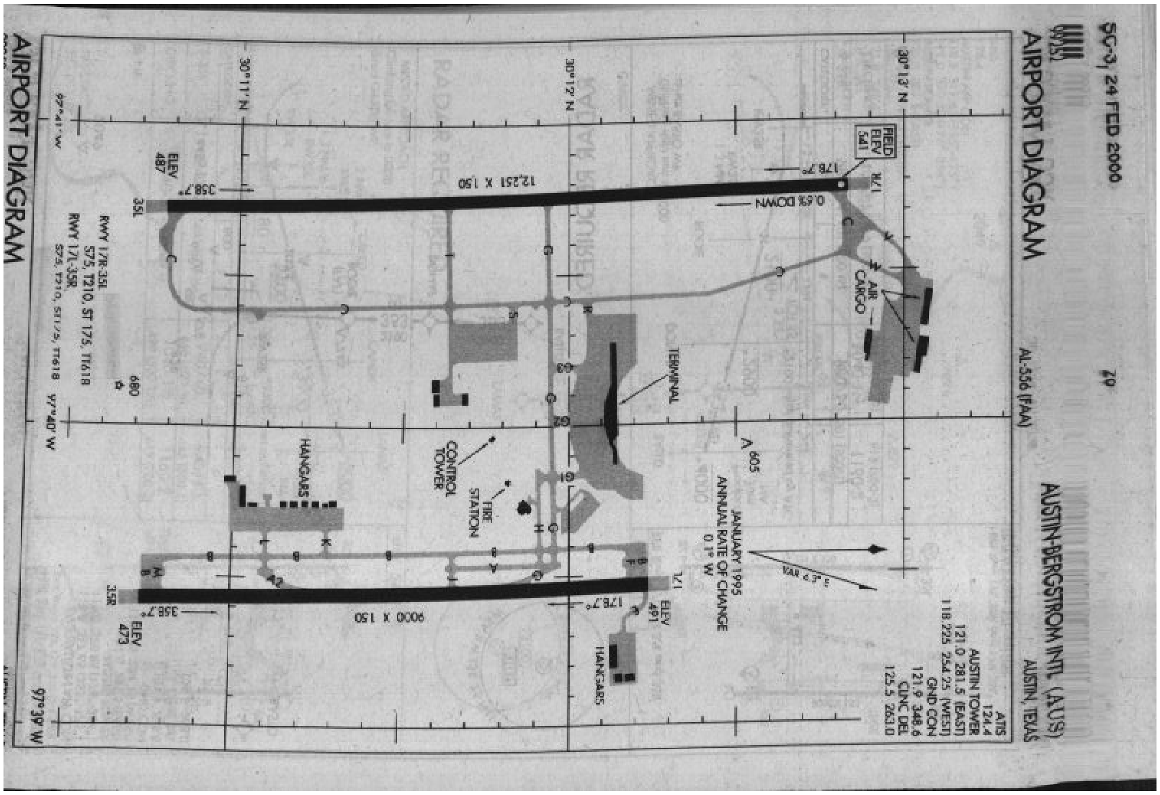


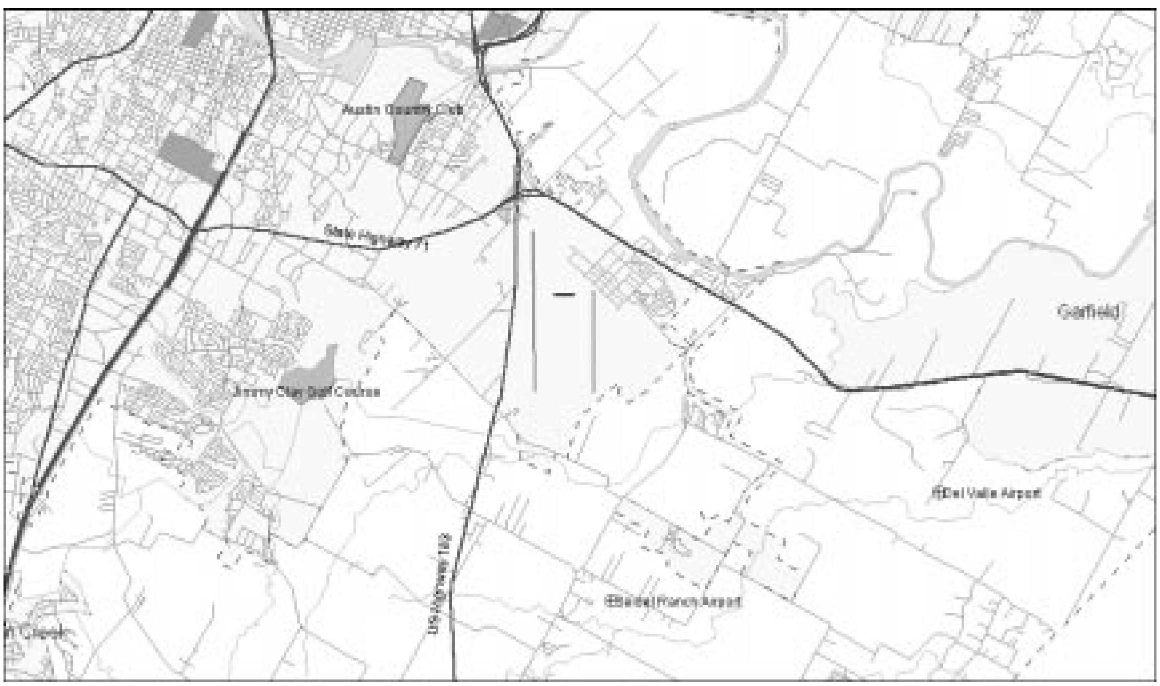


ATLANTA

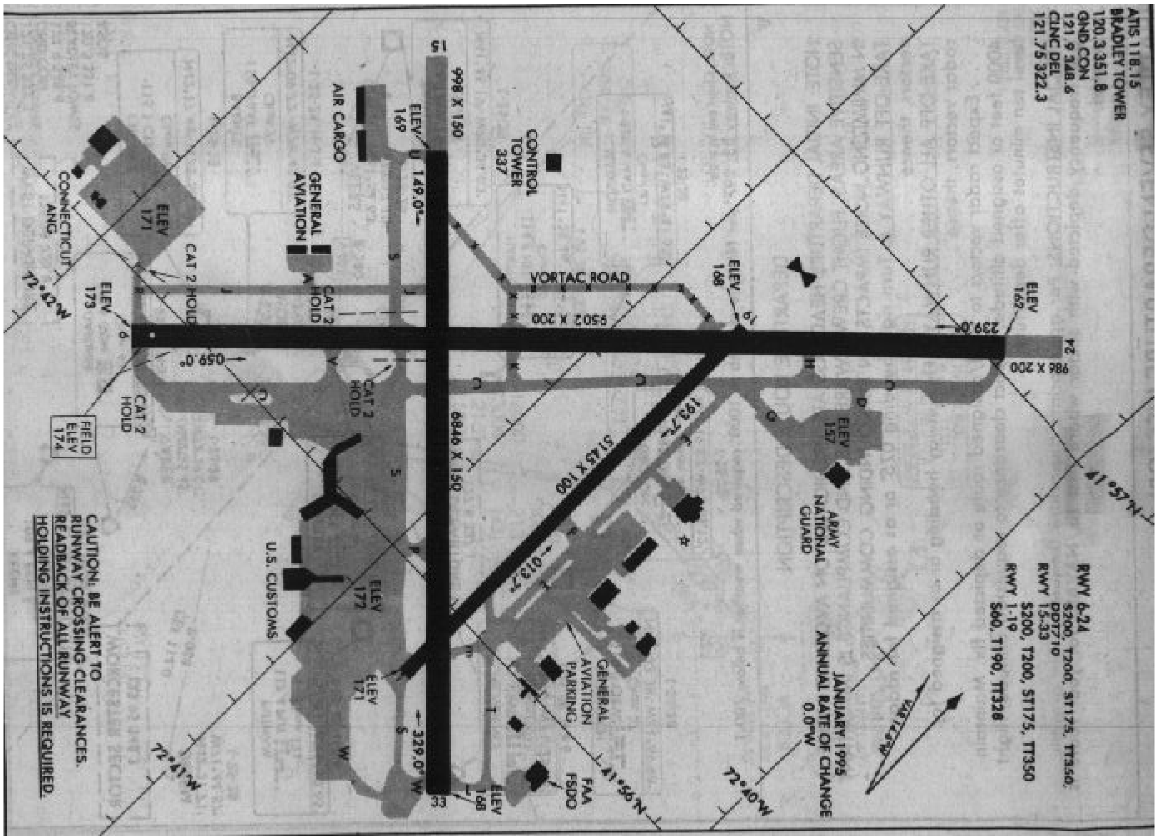

ALBUQUERQUE TOWER
118.3 351.9
GND CON
121.9 348.6
CLNC DEL
119.2 385.6
AIRPORT DIAGRAM
AL-12 (FAA)
ALBUQUERQUE INTL SUNPORT
ELEV 5318
CONTROL TOWER 5528
BASE OPS
TERMINAL
TERMINAL APRON
MILITARY OPERATIONS AREA AND HANGARS
APRON E ELEV 5325
FIRE STATION
ANG RAMP ELEV 5351
AIR FREIGHT APRON
ELEV 5310
RWY 12 ELEV 5310
NWS
GENERAL AVIATION AREA
AFSS
13,793 X 150
0.5% DOWN
079.6°
259.6°
10,000 X 150
6000 X 150
ELEV 5315
FIRE STATION
BUILDING
ARM-DEARM APRON
FIELD ELEV 5352
PAD 5
ELEV 5312
BAK-12/14
BAK-9
ELEV 5316
JANUARY 1995 ANNUAL RATE OF CHANGE 0.0°W
Rwy 8 ldg 12,793'
Rwy 17 ldg 9110'
Rwy 35 ldg 9110'
RWYS 3-21
S100, T210, TT360
RWYS 8-26 and 17-35
S100, T210, TT360, DDT350
RWY 12-30
S45, T65
AIR FREIGHT APRON
ELEV 5310
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES. READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
35°03'N
35°02'N
106°37'W
106°36'W
106°35'W

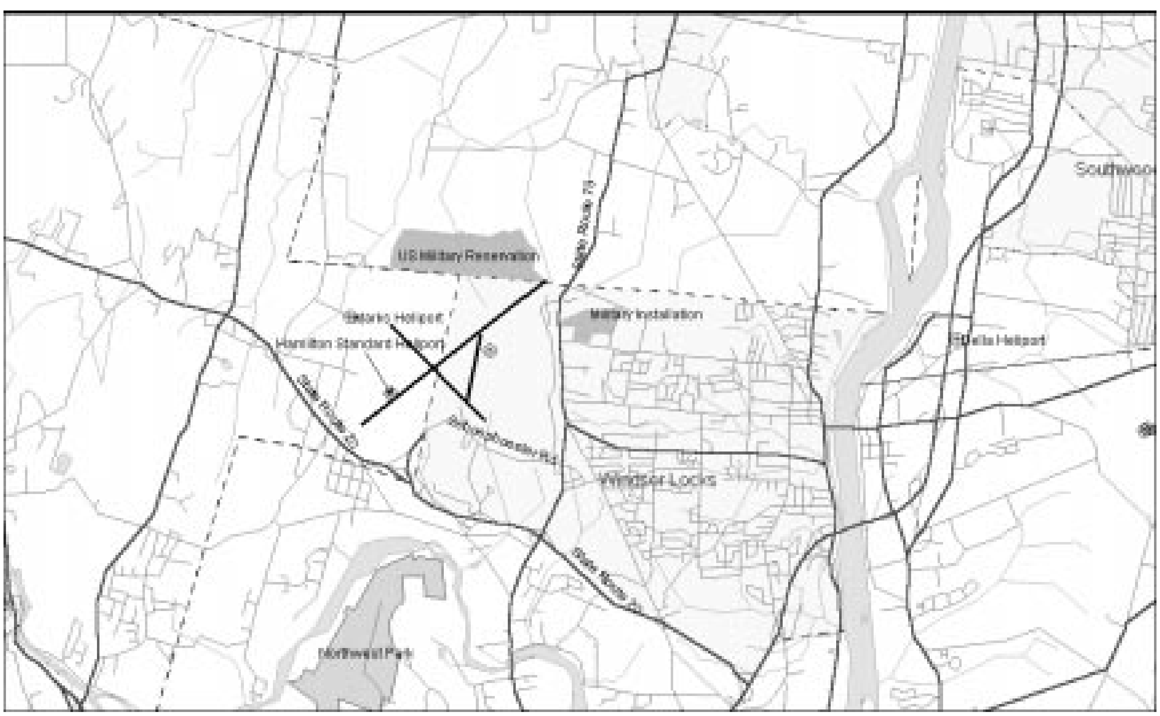
AUSTIN


AIRPORT DIAGRAM
AUSTIN-BERGSTROM INTL (AUS)
AUSTIN, TEXAS
TERMINAL
CONTROL TOWER
FIRE STATION
HANGARS
AIR CARGO

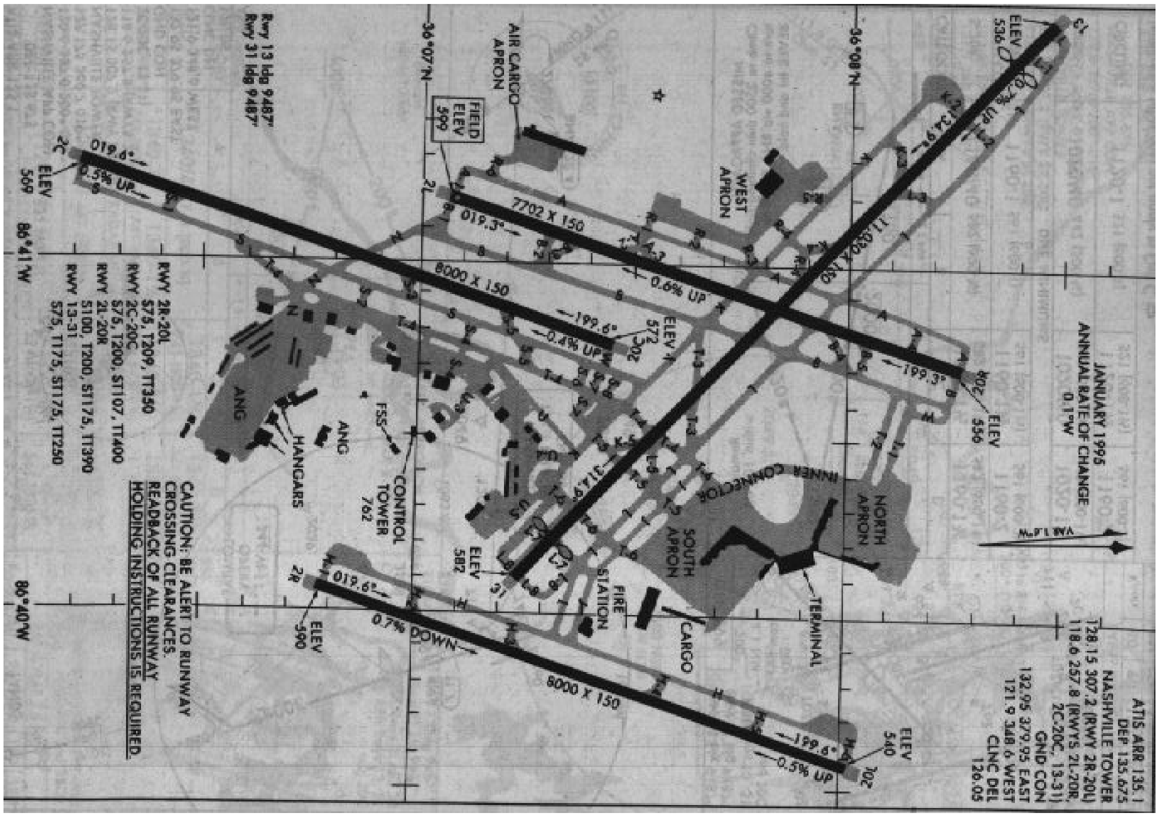

Austin Country Club
Garfield
Del Valle Airport

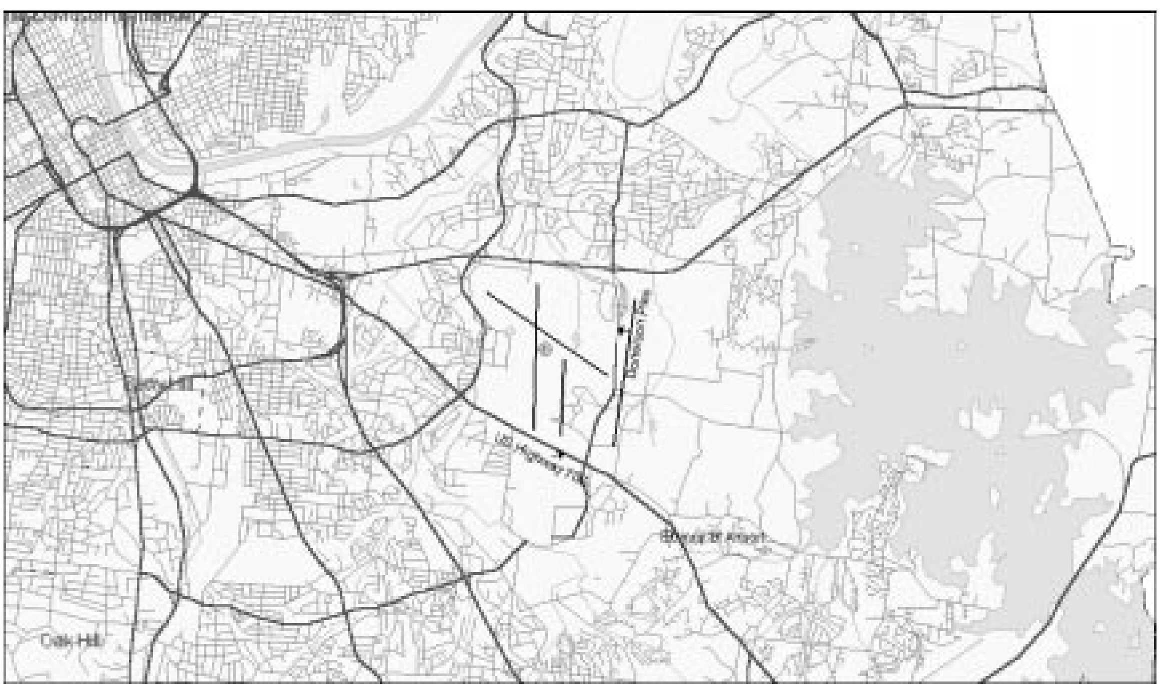
BRADLEY


ATIS 118.15
BRADLEY TOWER
120.3 351.8
GND CON
121.9 348.6
CLNC DEL
121.75 322.3
CONTROL TOWER 337
AIR CARGO
GENERAL AVIATION
CONNECTICUT ANG
VORTAC ROAD
9502 X 200
6846 X 150
5145 X 100
998 X 150
U.S. CUSTOMS
ARMY NATIONAL GUARD
GENERAL AVIATION PARKING
FAA FSDO
JANUARY 1995 ANNUAL RATE OF CHANGE 0.0°W
FIELD ELEV 174
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES. READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.

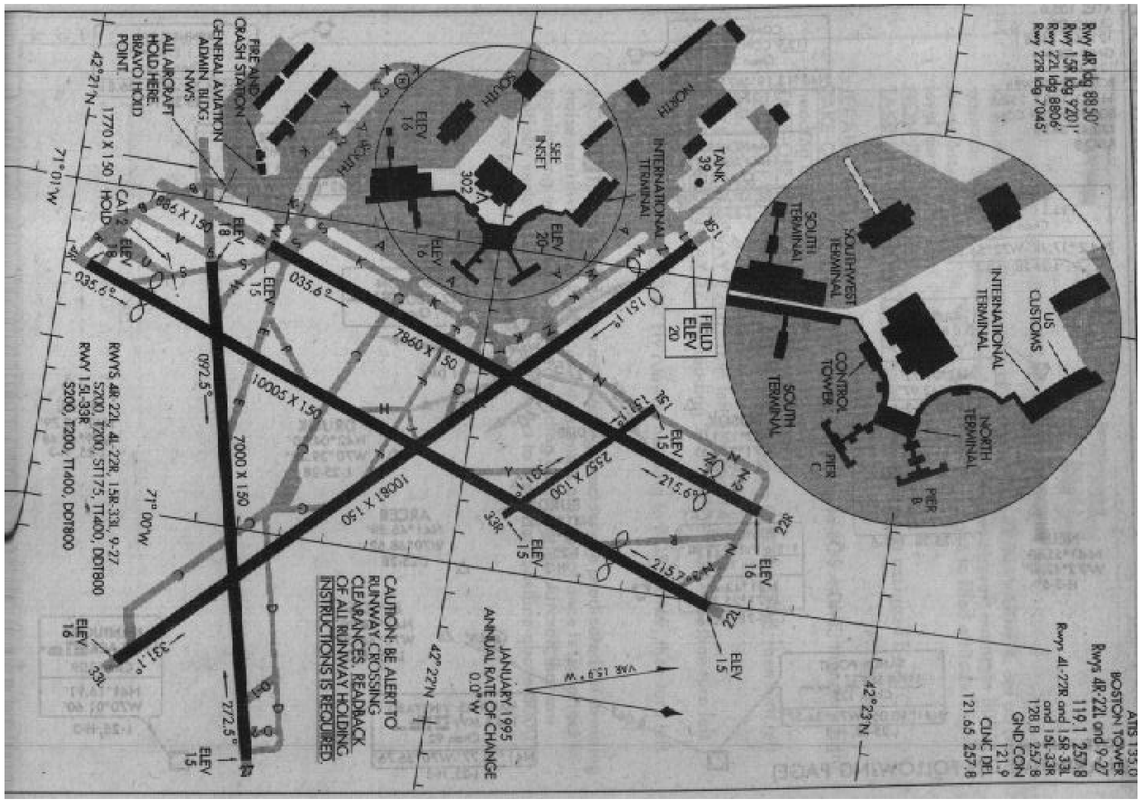

U.S Military Reservation
Military Installation
Hamilton Standard Heliport
Windsor Locks
Northwest Park

NASHVILLE



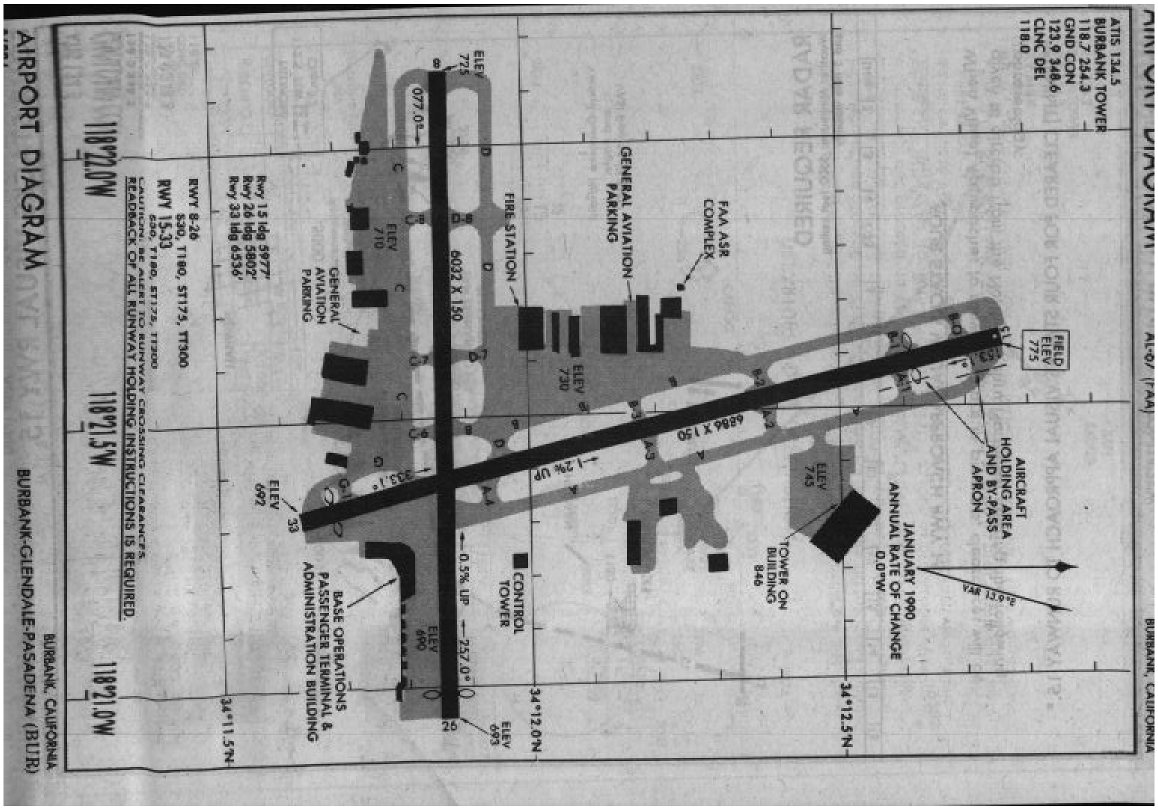


BOSTON



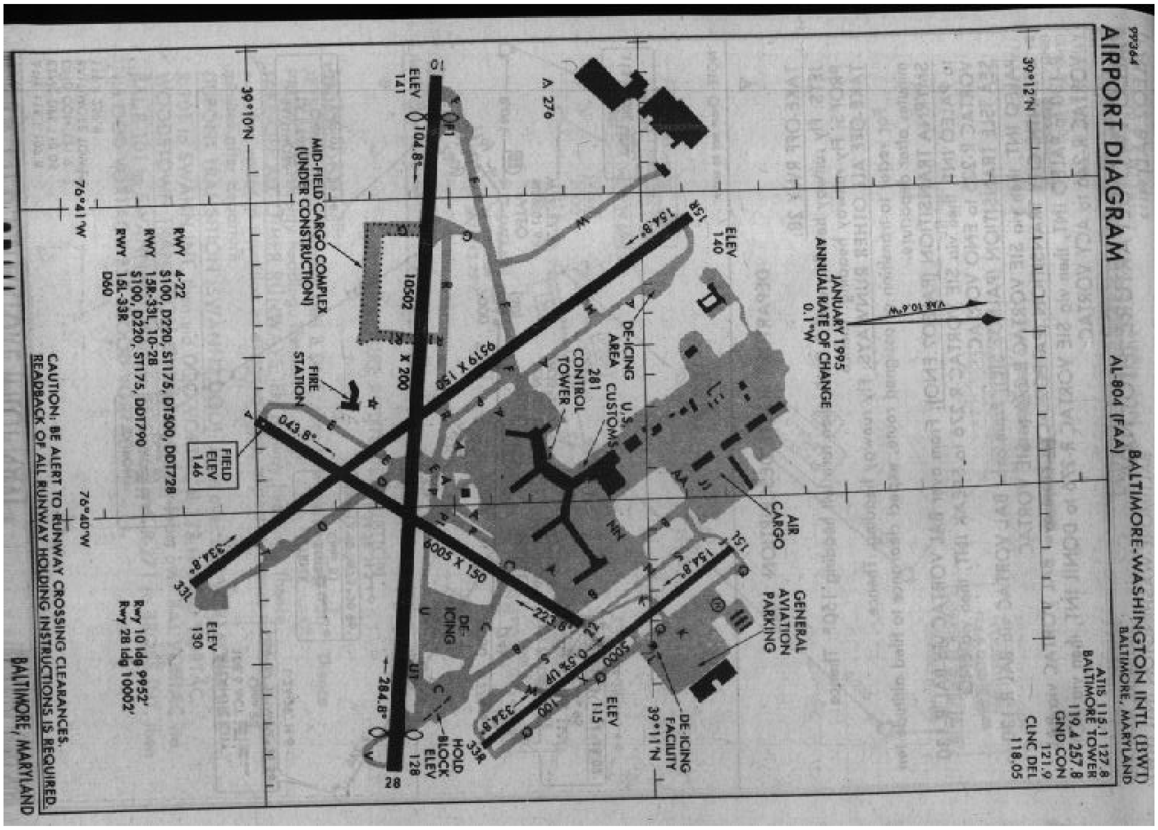
BOSTON

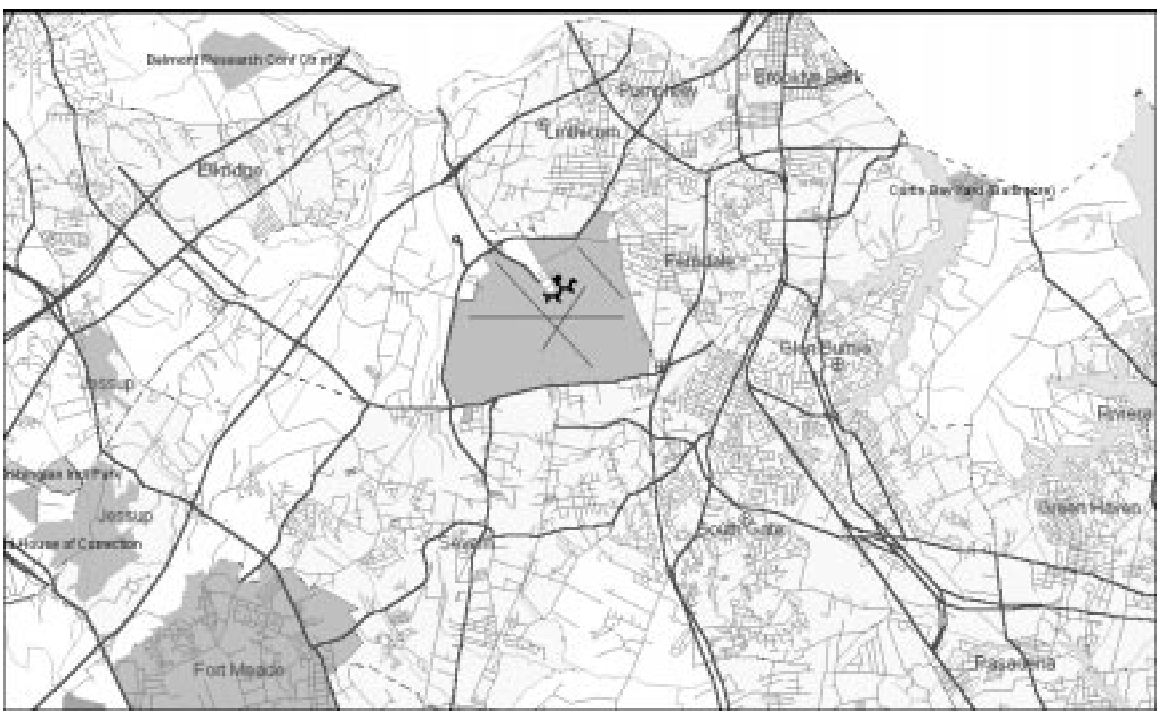
BURBANK


AIRPORT DIAGRAM
BURBANK, CALIFORNIA
BURBANK-GLENDALE-PASADENA (BUR)
ATIS 134.5
BURBANK TOWER
118.7 254.3
GND CON
123.9 348.6
CLNC DEL
118.0
FIELD ELEV 775
FAA ASR COMPLEX
GENERAL AVIATION PARKING
FIRE STATION
6032 X 150
6886 X 150
CONTROL TOWER
TOWER ON BUILDING 846
AIRCRAFT HOLDING AREA AND BY-PASS APRON
JANUARY 1990
ANNUAL RATE OF CHANGE
0.0°W
VAR 13.9°E
BASE OPERATIONS
PASSENGER TERMINAL &
ADMINISTRATION BUILDING
Rwy 15 ldg 5977'
Rwy 26 ldg 5802'
Rwy 33 ldg 6536'
RWY 8-26
S30, T180, ST175, TT300
RWY 15-33
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES.
READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
34°11.5'N
34°12.0'N
34°12.5'N
118°22.0'W
118°21.5'W
118°21.0'W

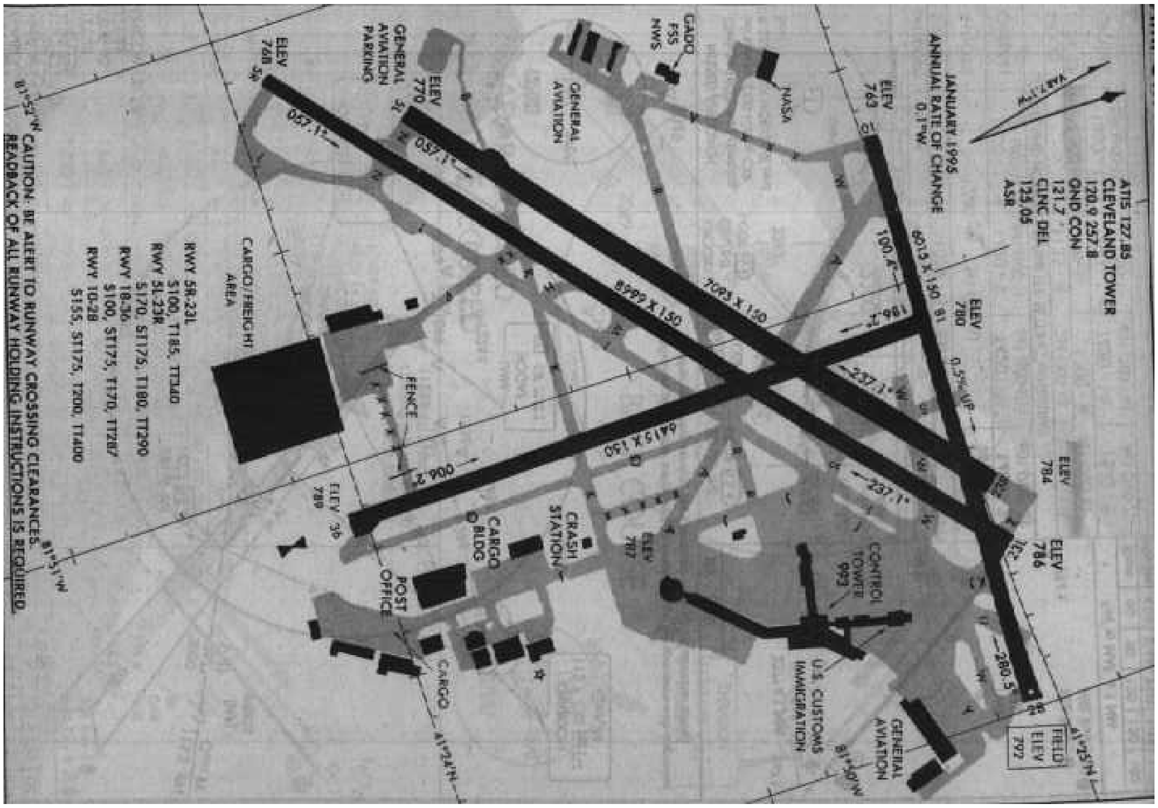

Sherman Way
Tujunga Ave
Vineland Ave
Vanowen St
W Vanowen St
N Hollywood Way
W Empire Ave
Burbank

BALTIMORE


AIRPORT DIAGRAM
AL-804 (FAA)
BALTIMORE-WASHINGTON INTL (BWI)
BALTIMORE, MARYLAND
JANUARY 1995
ANNUAL RATE OF CHANGE
0.1°W
MID-FIELD CARGO COMPLEX
(UNDER CONSTRUCTION)
FIRE STATION
CONTROL TOWER
U.S. CUSTOMS
AIR CARGO
GENERAL AVIATION PARKING
DE-ICING FACILITY
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES.
READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
BALTIMORE, MARYLAND

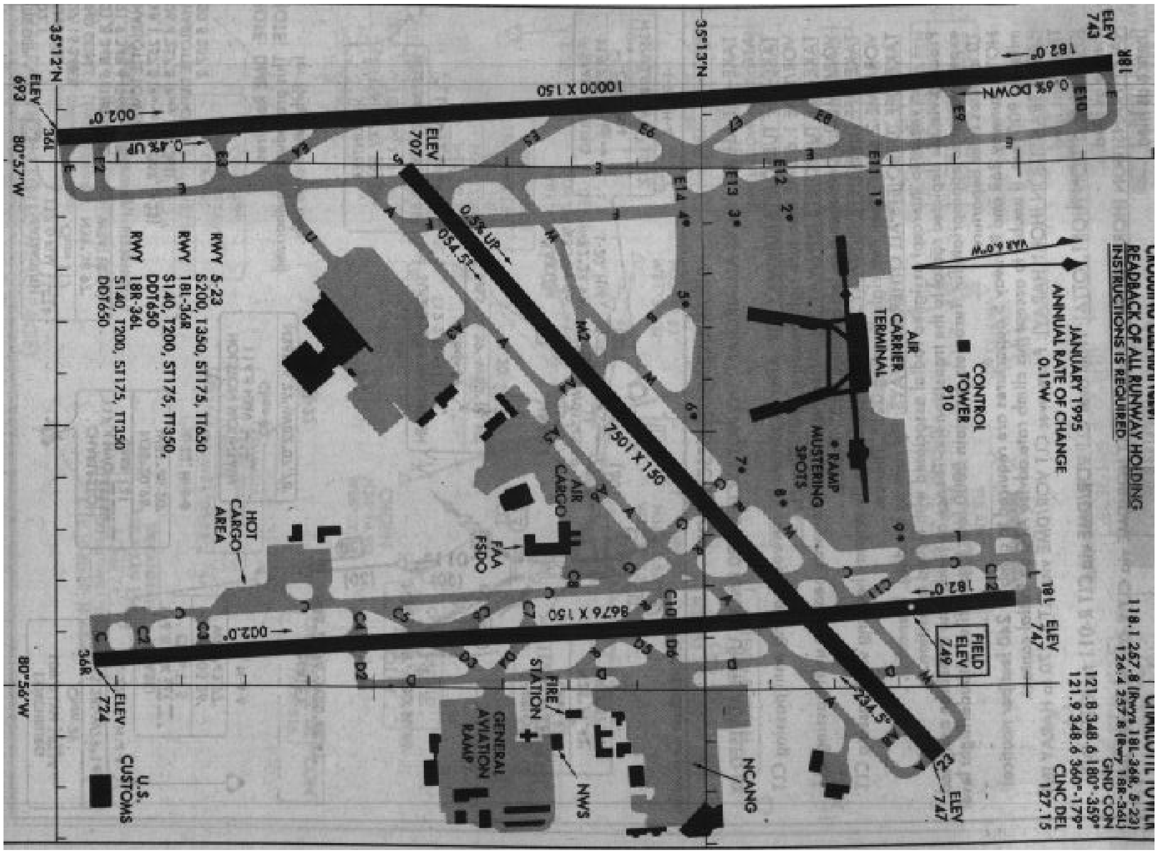

Linthicum
Elkridge
Ferndale
Glen Burnie
Jessup
Fort Meade
Pasadena

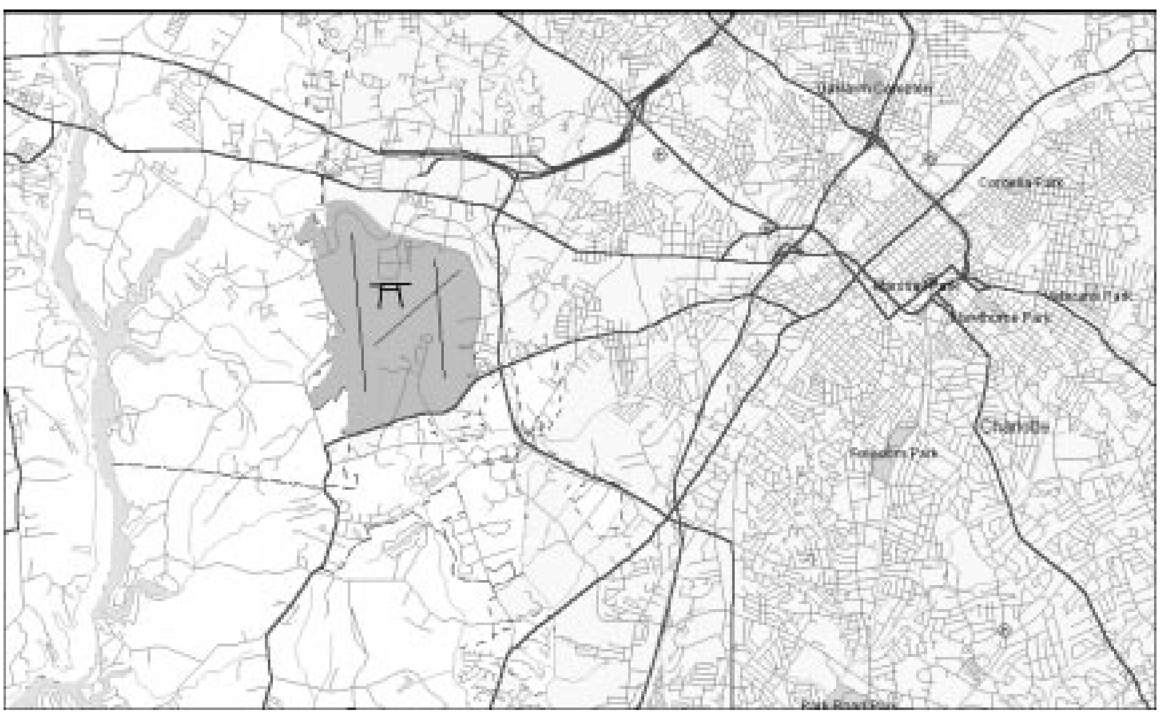
CLEVELAND



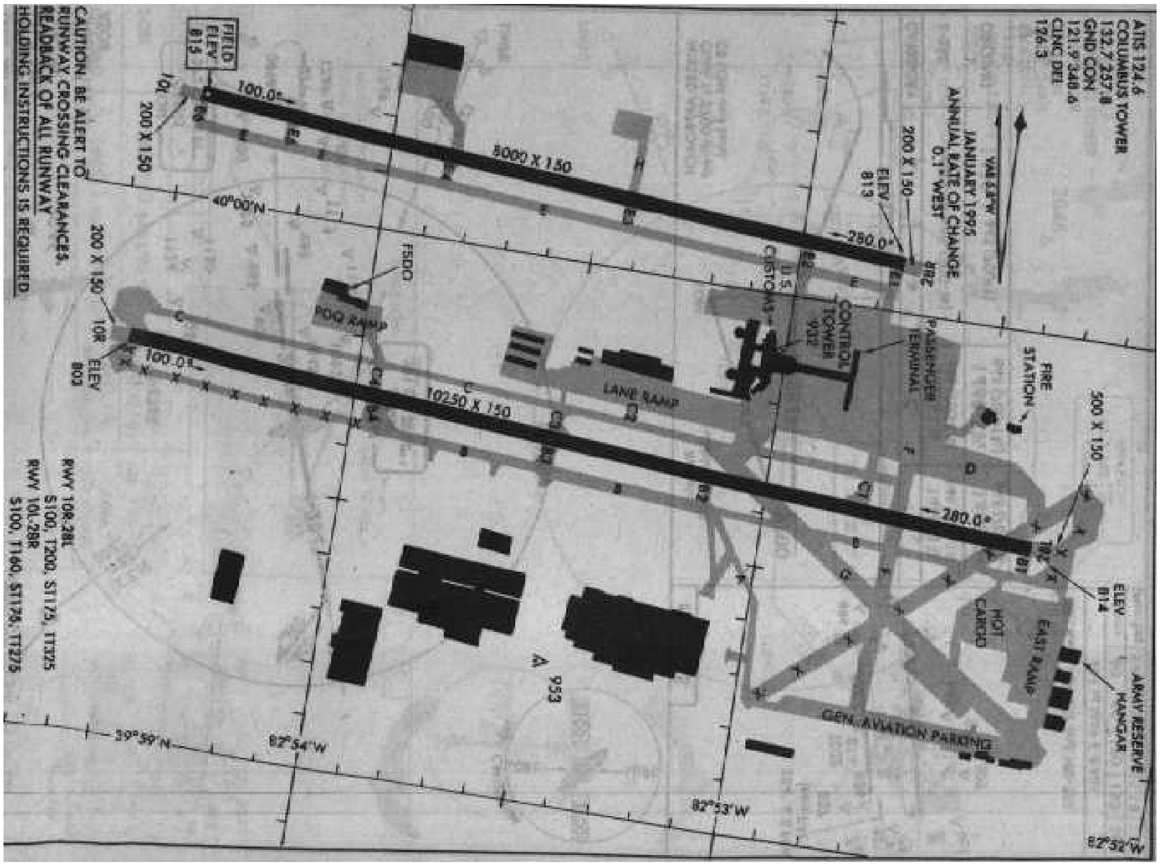
CLEVELAND

CHARLOTTE

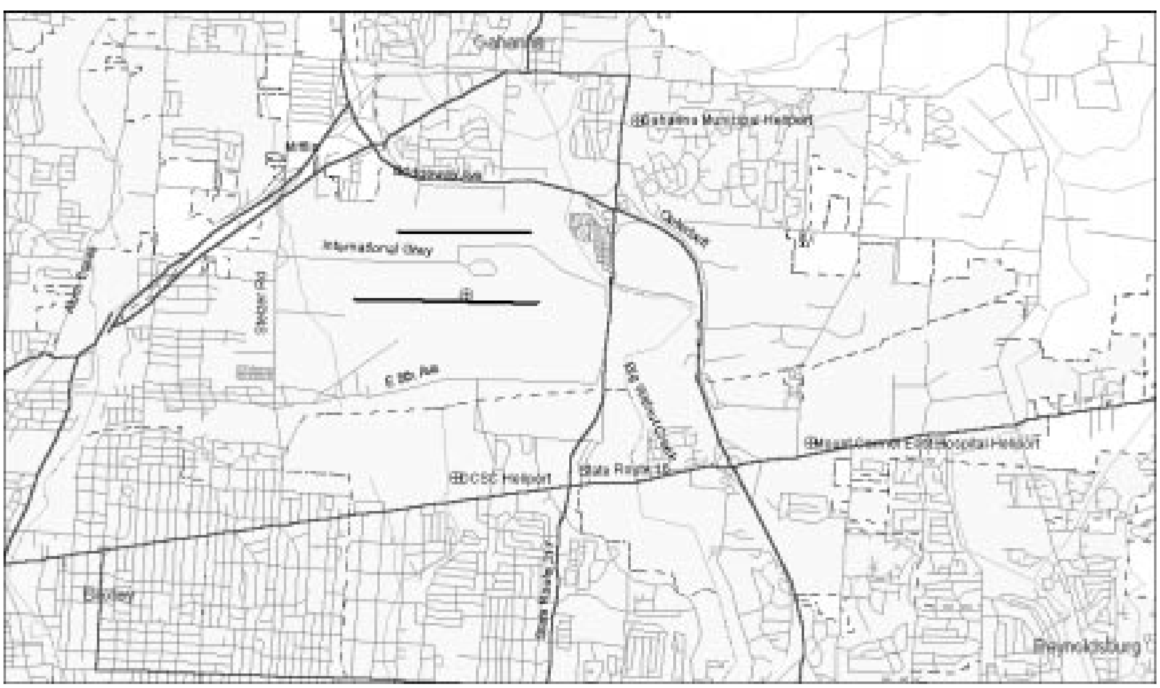

READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
JANUARY 1995
ANNUAL RATE OF CHANGE
0.1°W
CONTROL TOWER 910
AIR CARRIER TERMINAL
RAMP MUSTERING SPOTS
10000 X 150
7501 X 150
8676 X 150
AIR CARGO
HOT CARGO AREA
FAA FSDO
FIRE STATION
GENERAL AVIATION RAMP
NWS
NCANG
U.S. CUSTOMS
FIELD ELEV 749



COLUMBUS



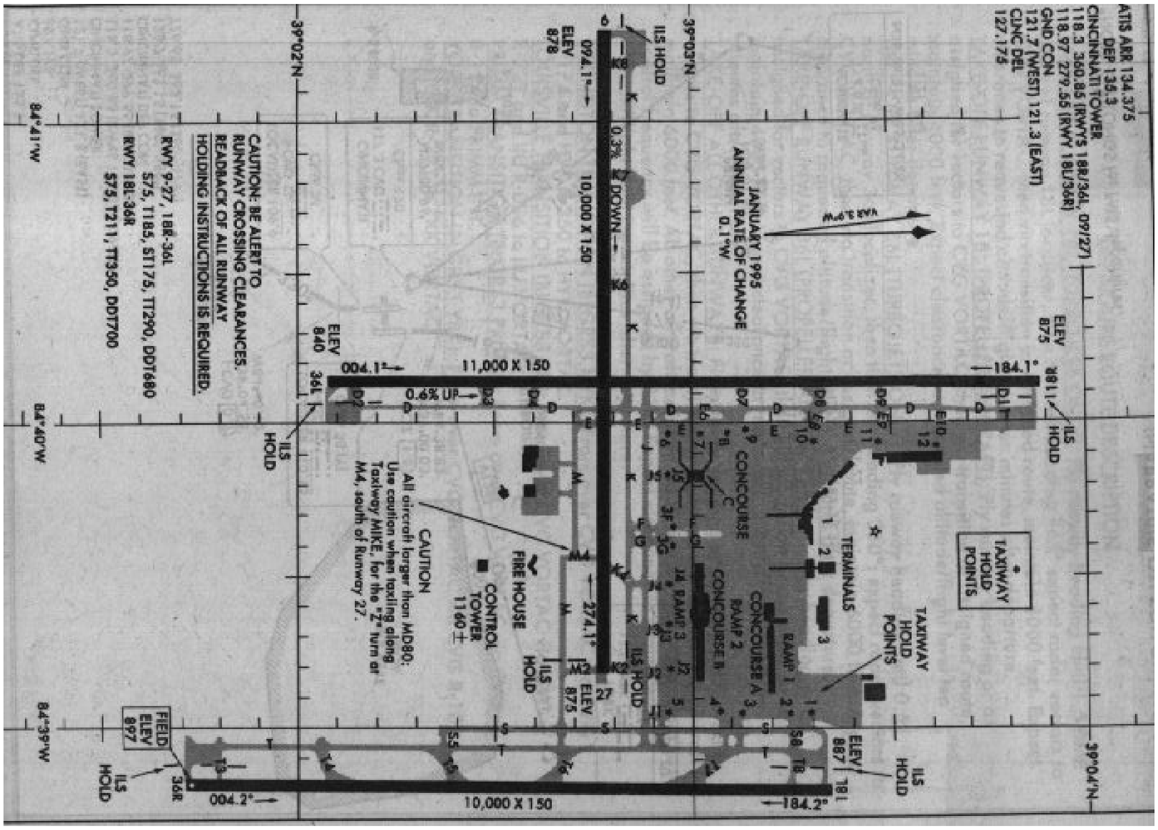
ATIS 124.6
COLUMBUS TOWER
132.7 257.8
GND CON
121.9 348.6
CLNC DEL
126.3
VAR 5.8°W
JANUARY 1995
ANNUAL RATE OF CHANGE
0.1° WEST
FIELD
ELEV
815
CAUTION: BE ALERT TO
RUNWAY CROSSING CLEARANCES.
READBACK OF ALL RUNWAY
HOLDING INSTRUCTIONS IS REQUIRED.
8000 X 150
10250 X 150
200 X 150
500 X 150
100.0°
280.0°
FSDO
LANE RAMP
CONTROL
TOWER
PASSENGER
TERMINAL
U.S.
CUSTOMS
FIRE
STATION
HOT
CARGO
EAST RAMP
ARMY RESERVE
HANGAR
GEN. AVIATION PARKING
RWY 10R-28L
S100, T200, ST175, TT325
RWY 10L-28R
S100, T160, ST175, TT275
40°00'N
39°59'N
82°54'W
82°53'W
82°52'W

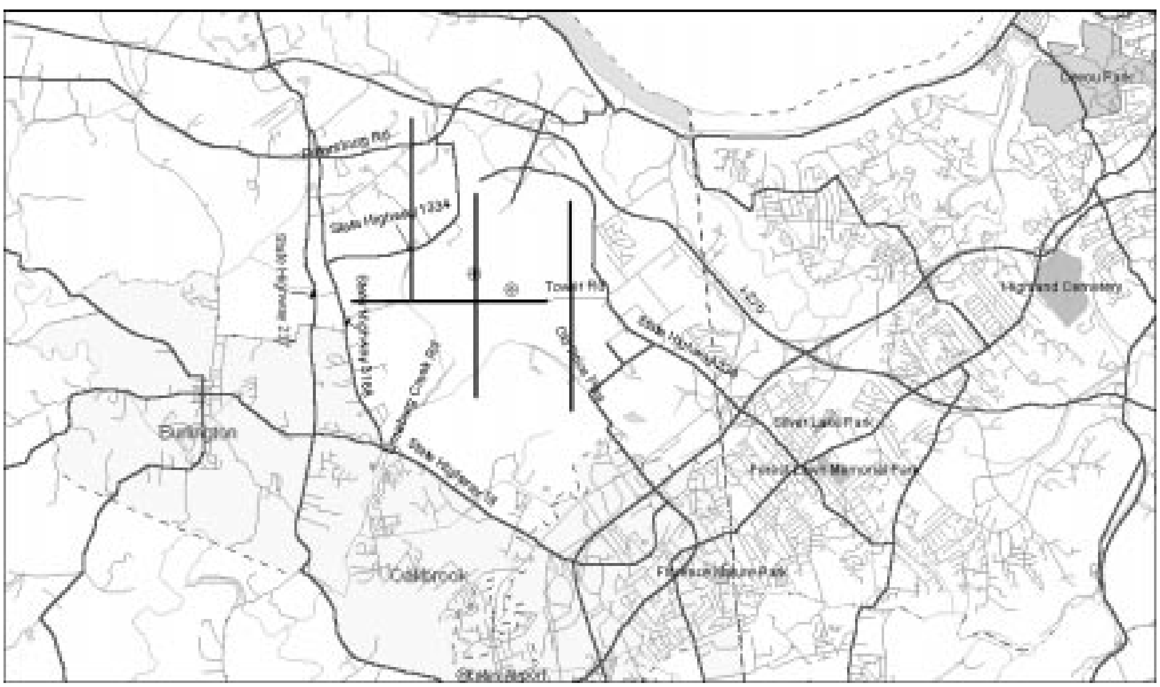


Gahanna
Gahanna Municipal Heliport
International Gtwy
E 5th Ave
State Route 16
CSC Heliport
Mount Carmel East Hospital Heliport
Bexley
Reynoldsburg

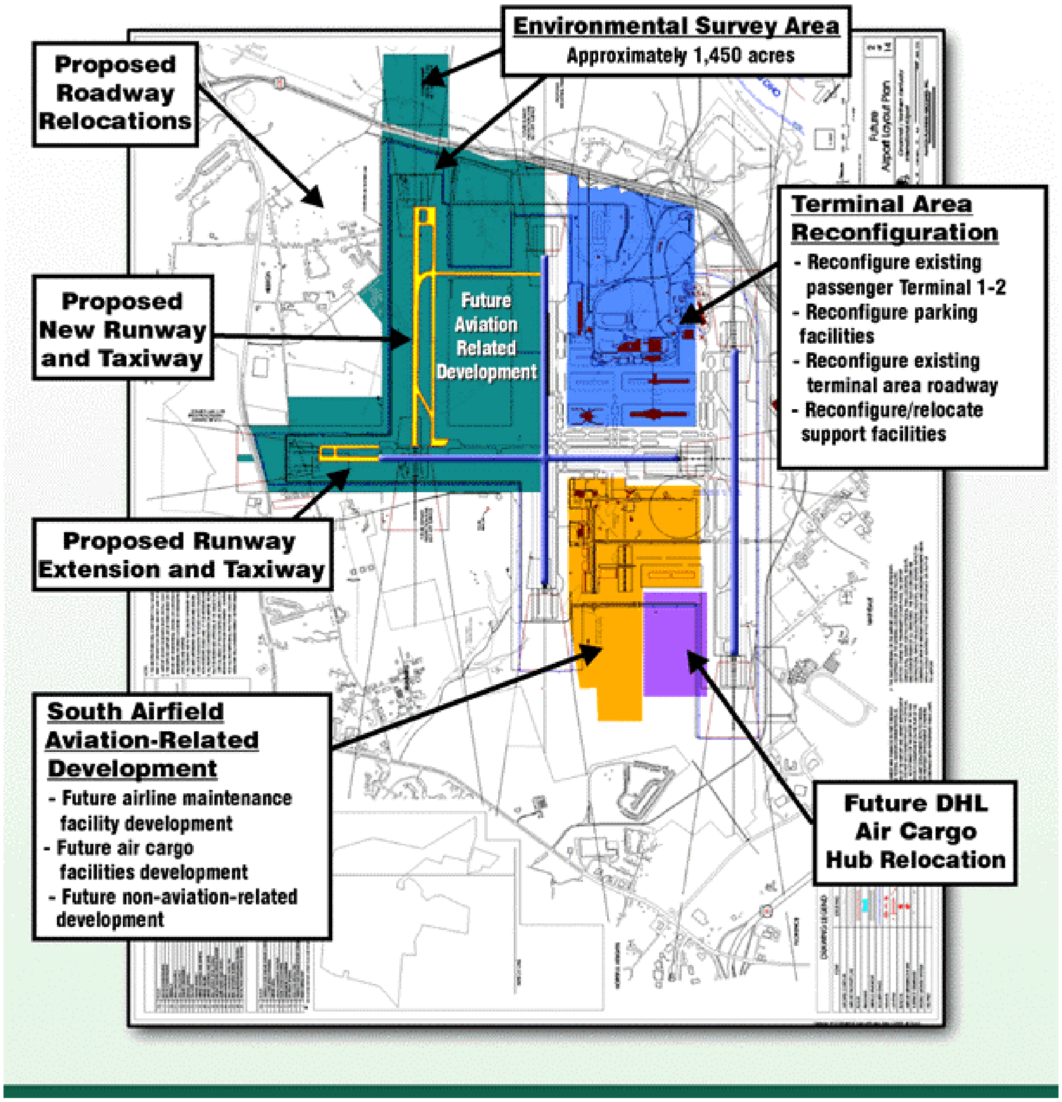
COLUMBUS

CINCINNATI

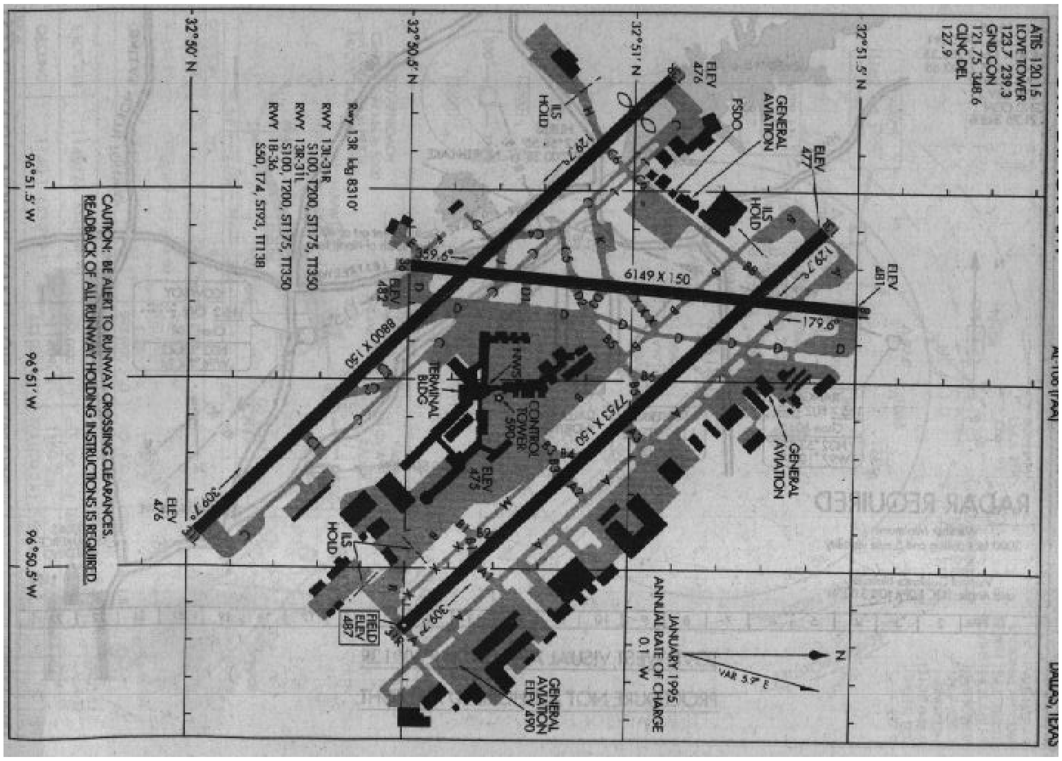

ATIS ARR 134.375
DEP 135.3
CINCINNATI TOWER
GND CON
CLNC DEL
127.175
JANUARY 1995
ANNUAL RATE OF CHANGE
0.1°W
10,000 X 150
11,000 X 150
10,000 X 150
CONCOURSE C
TERMINALS
CONCOURSE B
CONCOURSE A
RAMP 1
RAMP 2
RAMP 3
TAXIWAY HOLD POINTS
FIRE HOUSE
CONTROL TOWER
1160±
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES. READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
FIELD ELEV 897
ILS HOLD
39°02'N
39°03'N
39°04'N
84°41'W
84°40'W
84°39'W

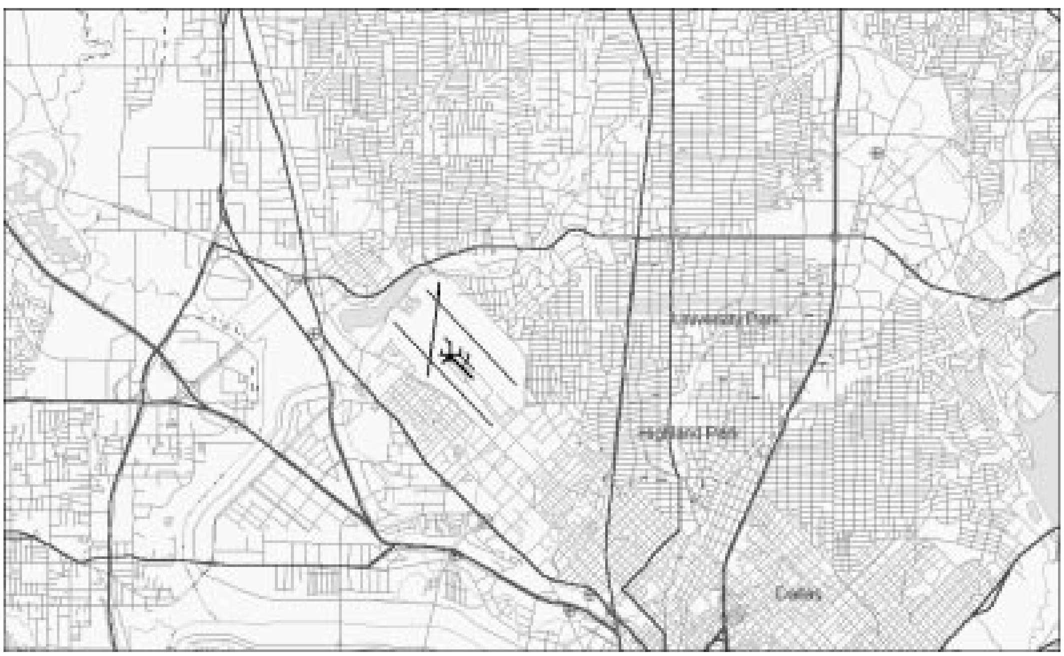

Tower Rd
State Highway 1334
Burlington
Highland Cemetery
Silver Lake Park

CINCINNATI (IMPROVEMENT PLANS)

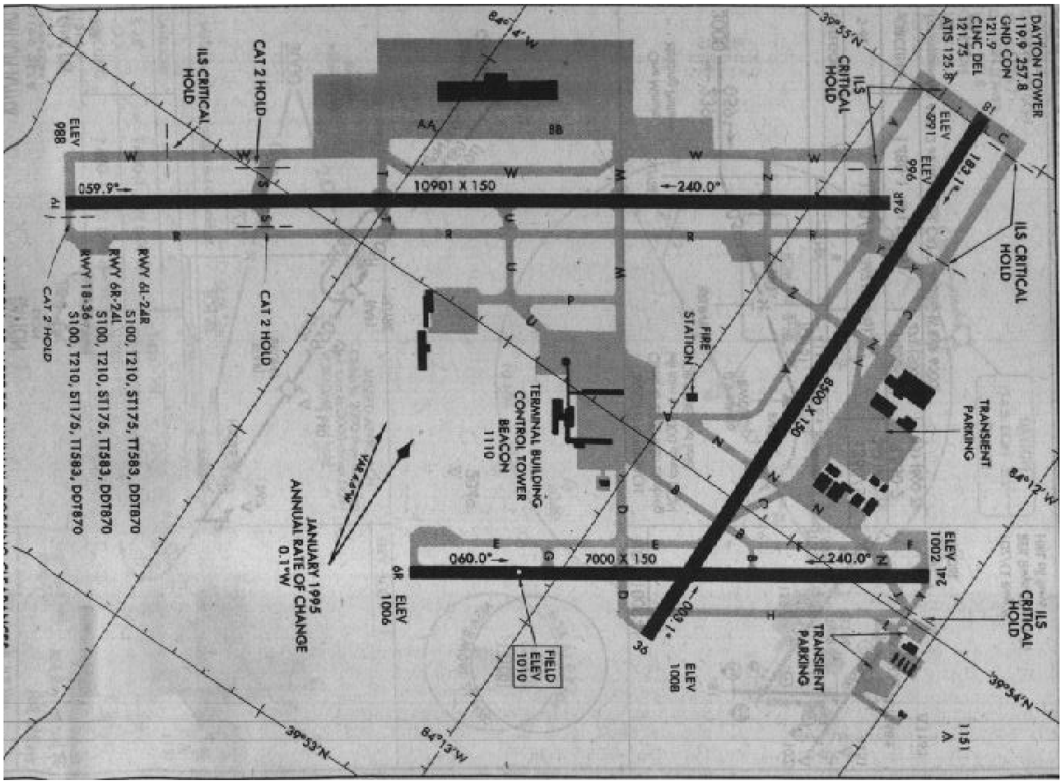


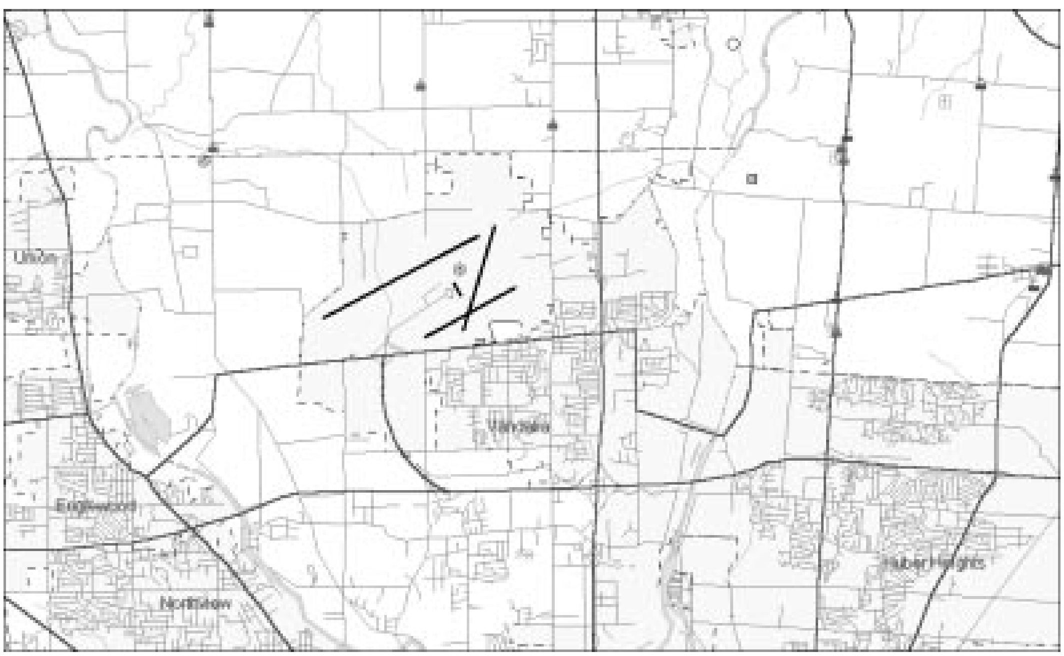
DALLAS LOVE FIELD



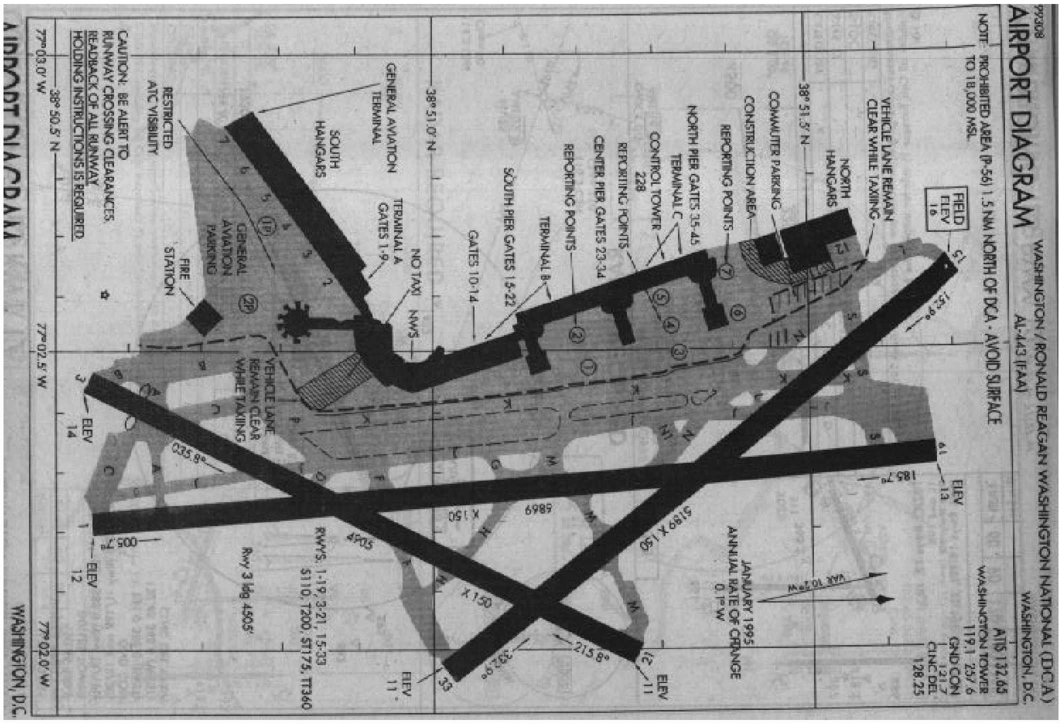


DAYTON

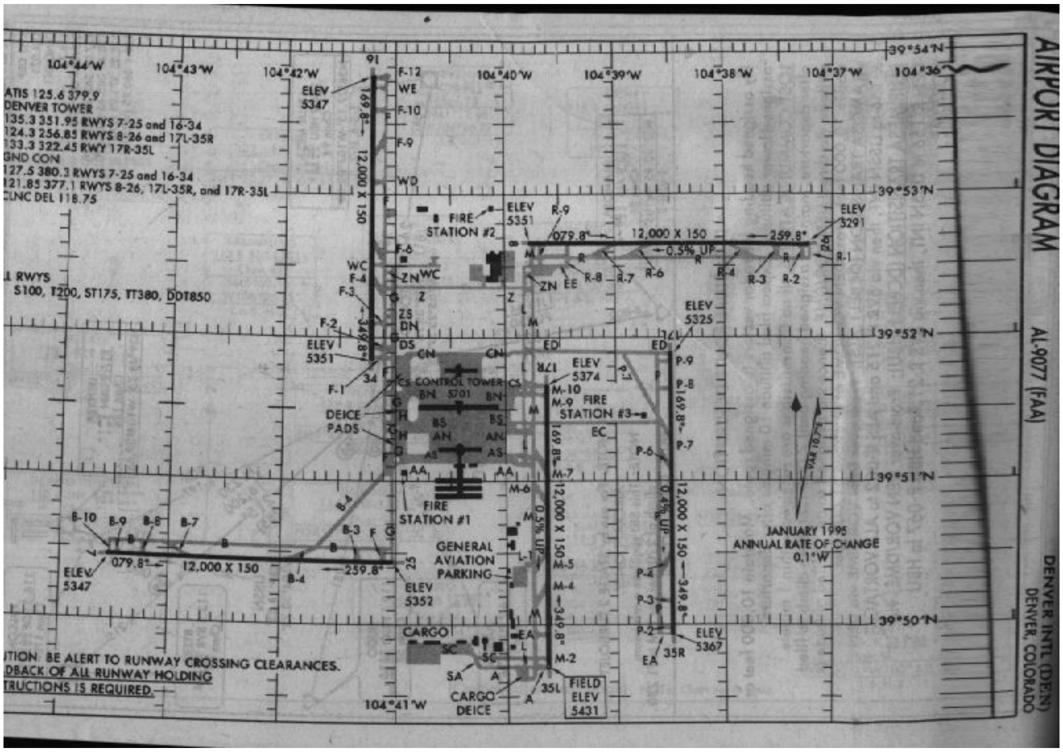




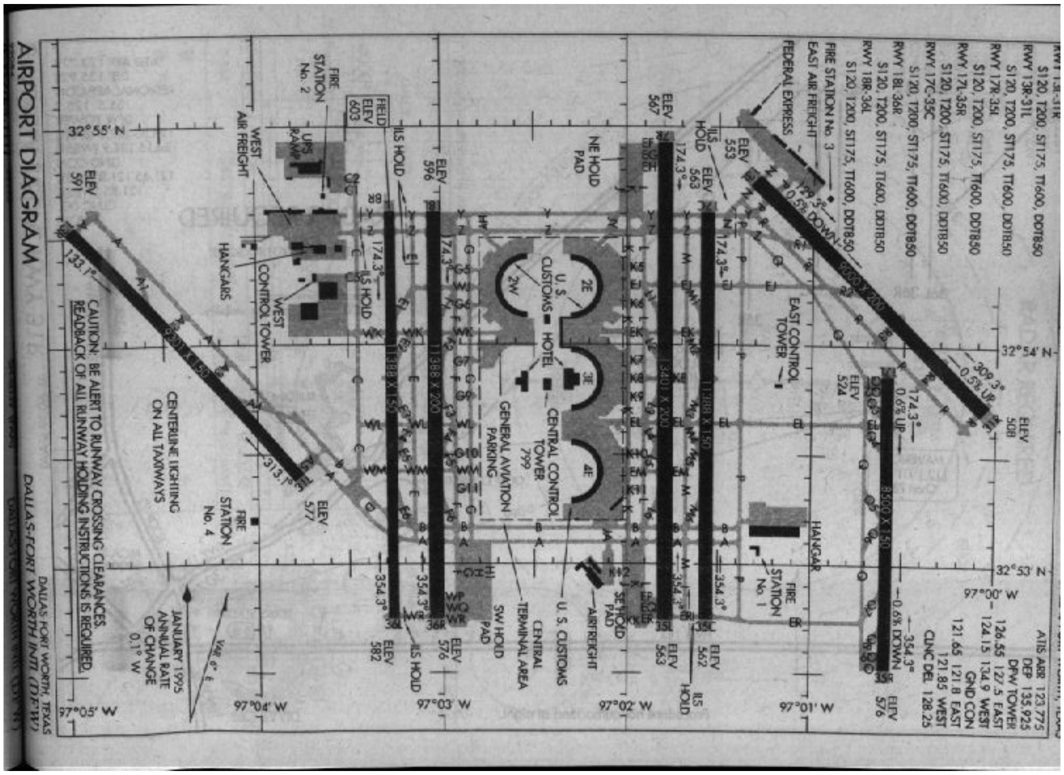
WASHINGTON NATIONAL

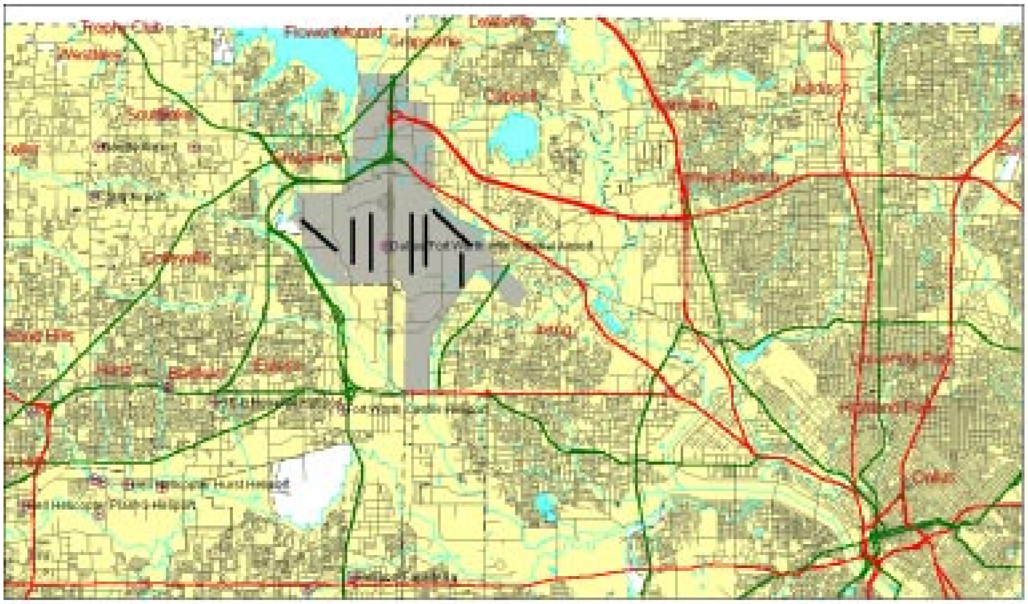


DENVER


AIRPORT DIAGRAM
AL-9077 (FAA)
DENVER INTL (DEN)
DENVER, COLORADO
ATIS 125.6 379.9
DENVER TOWER
135.3 351.95 RWYS 7-25 and 16-34
124.3 256.85 RWYS 8-26 and 17L-35R
133.3 322.45 RWY 17R-35L
GND CON
127.5 380.3 RWYS 7-25 and 16-34
121.85 377.1 RWYS 8-26, 17L-35R, and 17R-35L
CLNC DEL 118.75
S100, T200, ST175, TT380, DDT850
FIRE STATION #2
CONTROL TOWER
DEICE PADS
FIRE STATION #1
GENERAL AVIATION PARKING
CARGO
CARGO DEICE
FIRE STATION #3
FIELD ELEV 5431
JANUARY 1995
ANNUAL RATE OF CHANGE
0.1°W
BE ALERT TO RUNWAY CROSSING CLEARANCES.
DBACK OF ALL RUNWAY HOLDING
TRUCTIONS IS REQUIRED.

DALLAS-FORT WORTH



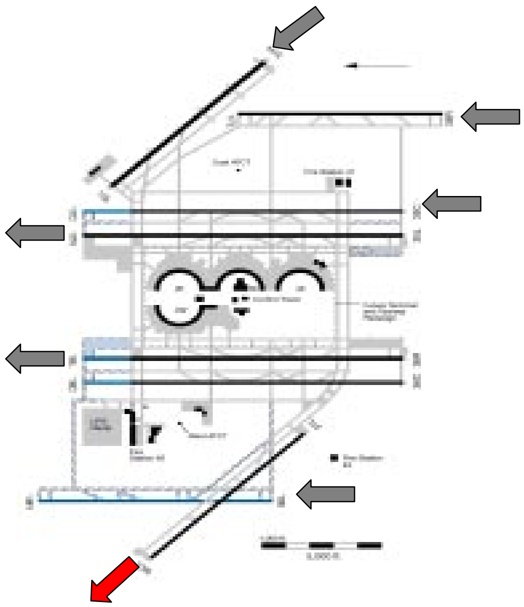


DALLAS-FORT WORTH

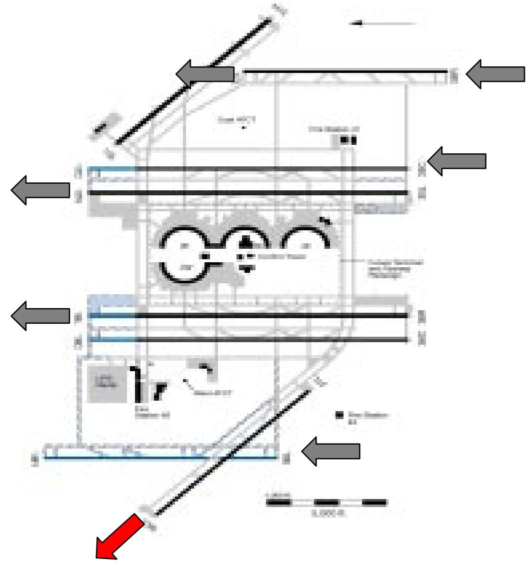
DALLAS-FORT WORTH CONFIGURATIONS

DFW

North MC 1&2

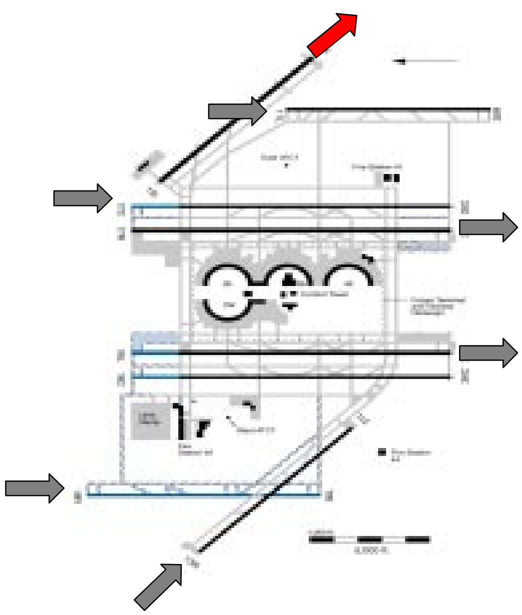


North MC 3&4

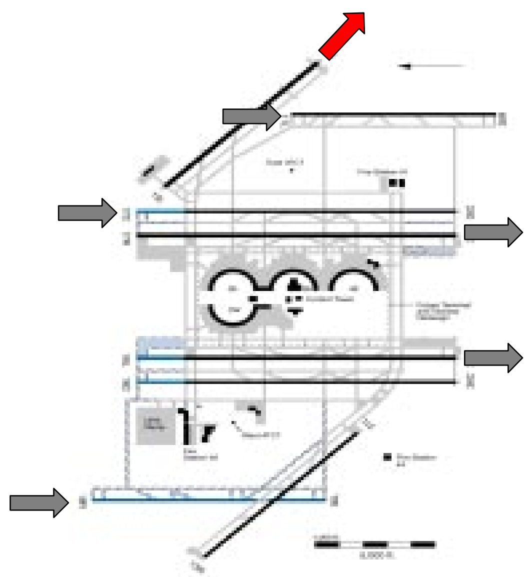


DFW

South MC 1&2

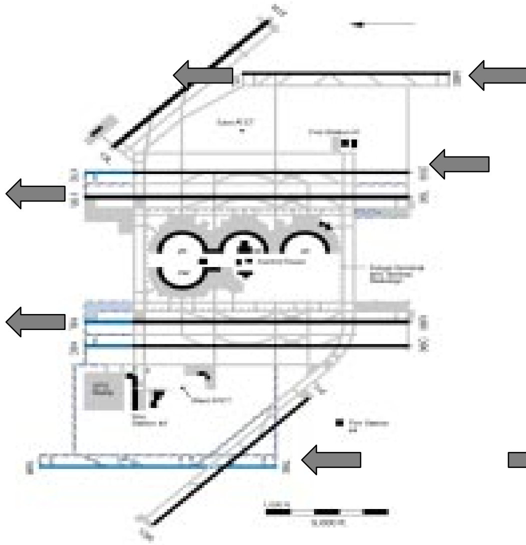


South MC 3&4

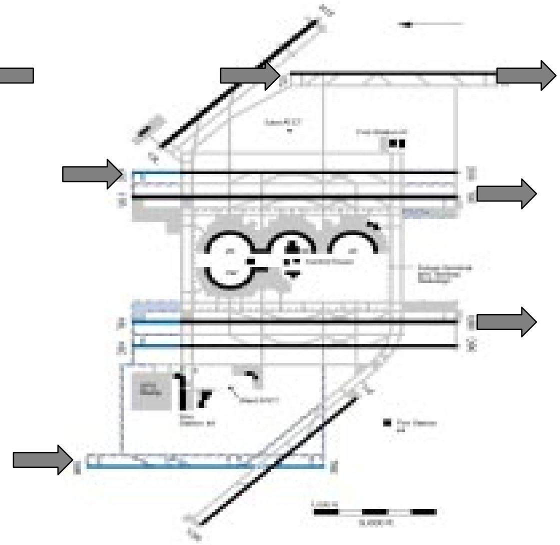


DALLAS-FORT WORTH CONFIGURATIONS

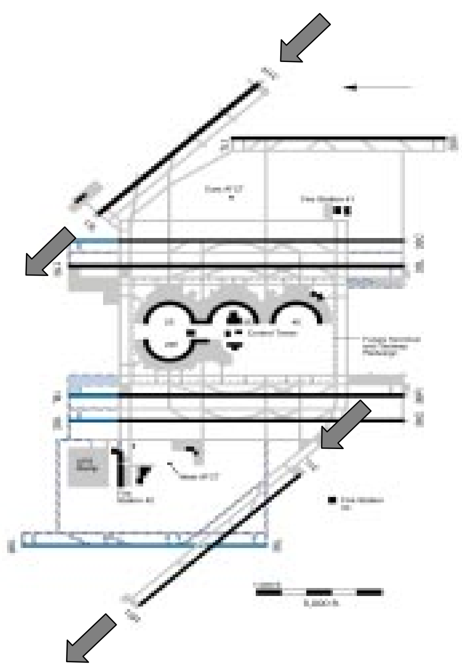
“No 31”



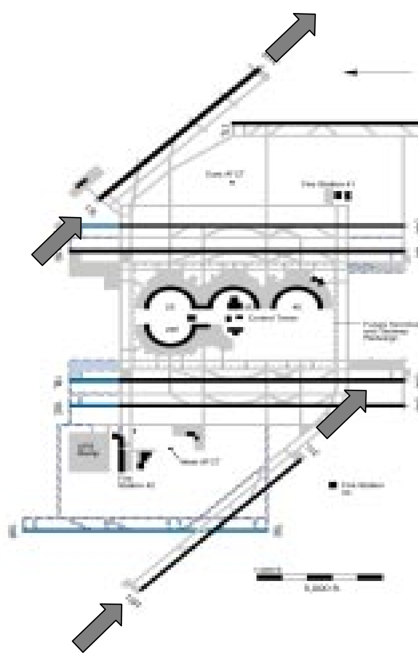
“No 13”



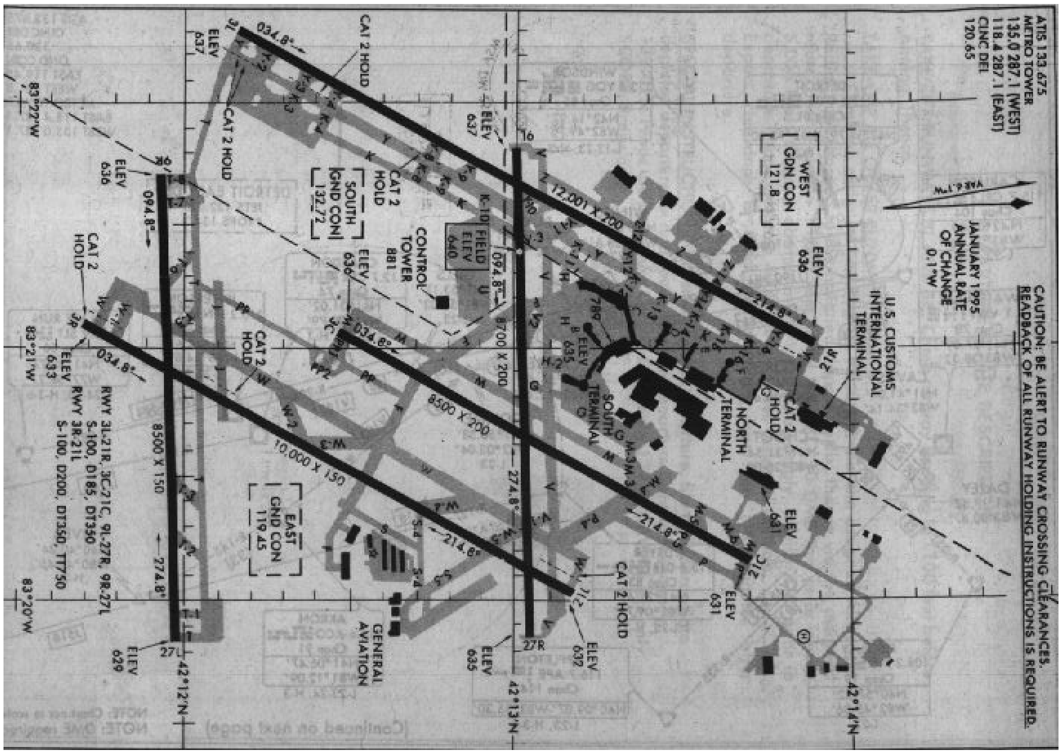
“Only 31”

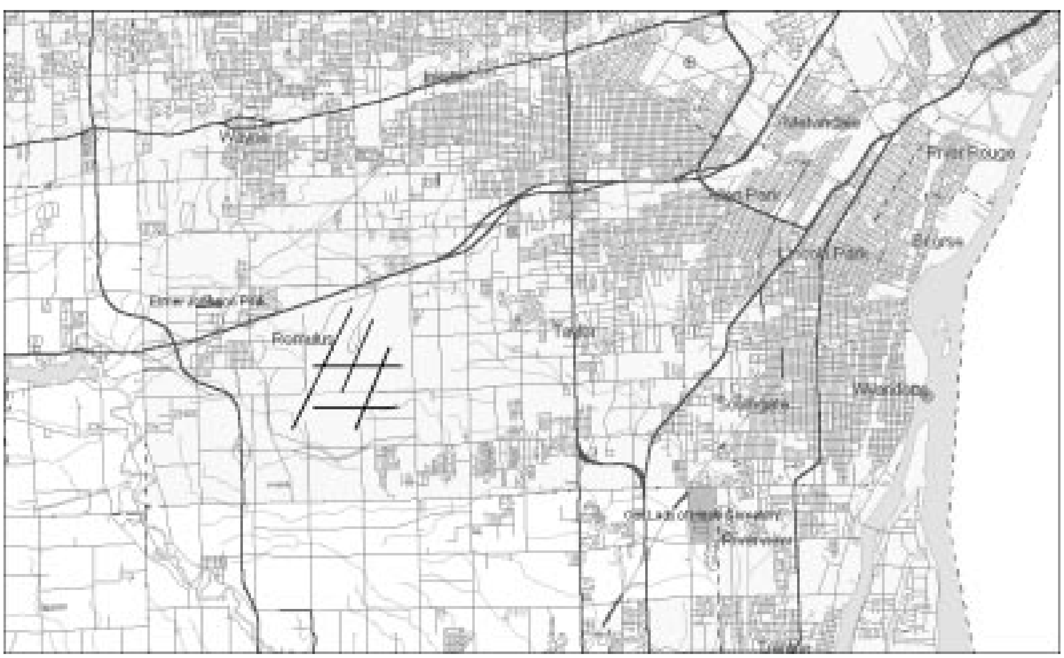


“Only 13”

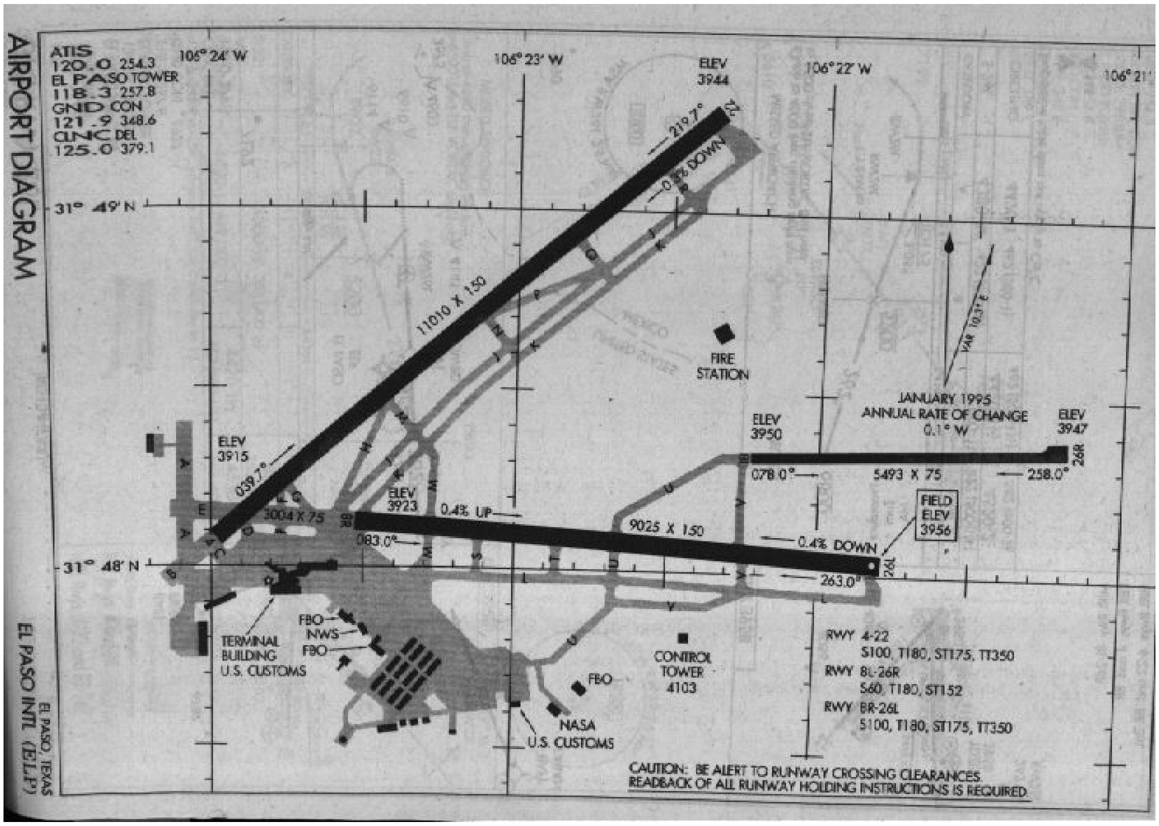


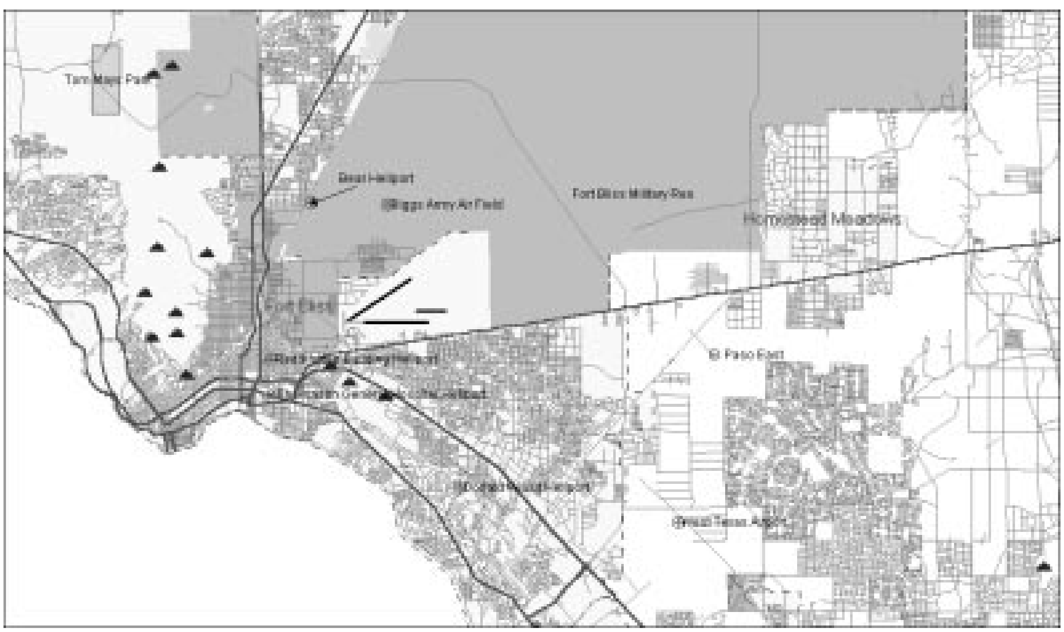
DETROIT


ATIS 133.675
METRO TOWER
135.0 287.1 (WEST)
118.4 287.1 (EAST)
CLNC DEL
120.65
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES. READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
JANUARY 1995
ANNUAL RATE
OF CHANGE
0.1°W
WEST
GND CON
121.8
SOUTH
GND CON
132.72
EAST
GND CON
119.45
CONTROL
TOWER
881
FIELD
ELEV
640
U.S. CUSTOMS
INTERNATIONAL
TERMINAL
NORTH
TERMINAL
SOUTH
TERMINAL
GENERAL
AVIATION
12,001 X 200
8700 X 200
8500 X 200
10,000 X 150
8500 X 150
RWY 3L-21R, 3C-21C, 9L-27R, 9R-27L
S-100, D185, DT350
RWY 3R-21L
S-100, D200, DT350, TT750
42°12'N
42°13'N
42°14'N
83°22'W
83°21'W
83°20'W

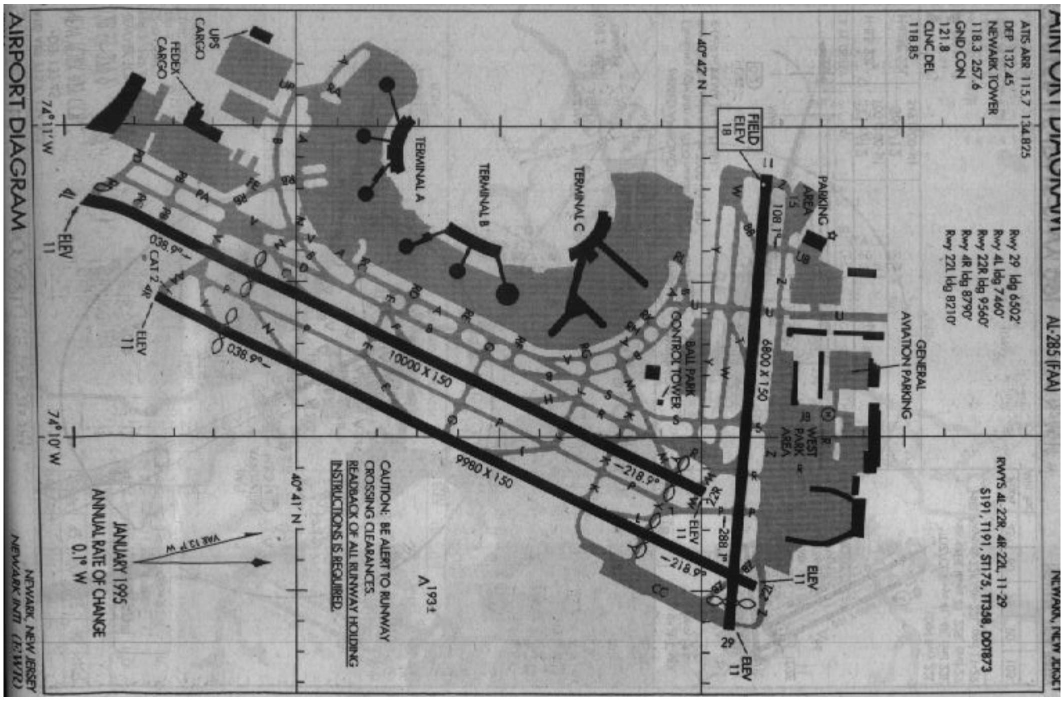


EL PASO


AIRPORT DIAGRAM
ATIS
120.0 254.3
EL PASO TOWER
118.3 257.8
GND CON
121.9 348.6
CLNC DEL
125.0 379.1
106° 24' W
106° 23' W
106° 22' W
31° 49' N
31° 48' N
ELEV 3944
219.7°
0.4% DOWN
11010 X 150
FIRE STATION
JANUARY 1995 ANNUAL RATE OF CHANGE 0.1° W
VAR 10.3° E
ELEV 3950
ELEV 3947
ELEV 3915
039.7°
3004 X 75
ELEV 3923
0.4% UP
078.0°
5493 X 75
258.0°
083.0°
9025 X 150
0.4% DOWN
FIELD ELEV 3956
263.0°
TERMINAL BUILDING U.S. CUSTOMS
FBO
NWS
FBO
CONTROL TOWER 4103
FBO
NASA
U.S. CUSTOMS
RWY 4-22
S100, T180, ST175, TT350
RWY 8L-26R
S60, T180, ST152
RWY 8R-26L
S100, T180, ST175, TT350
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES.
READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
EL PASO, TEXAS
EL PASO INTL (ELP)

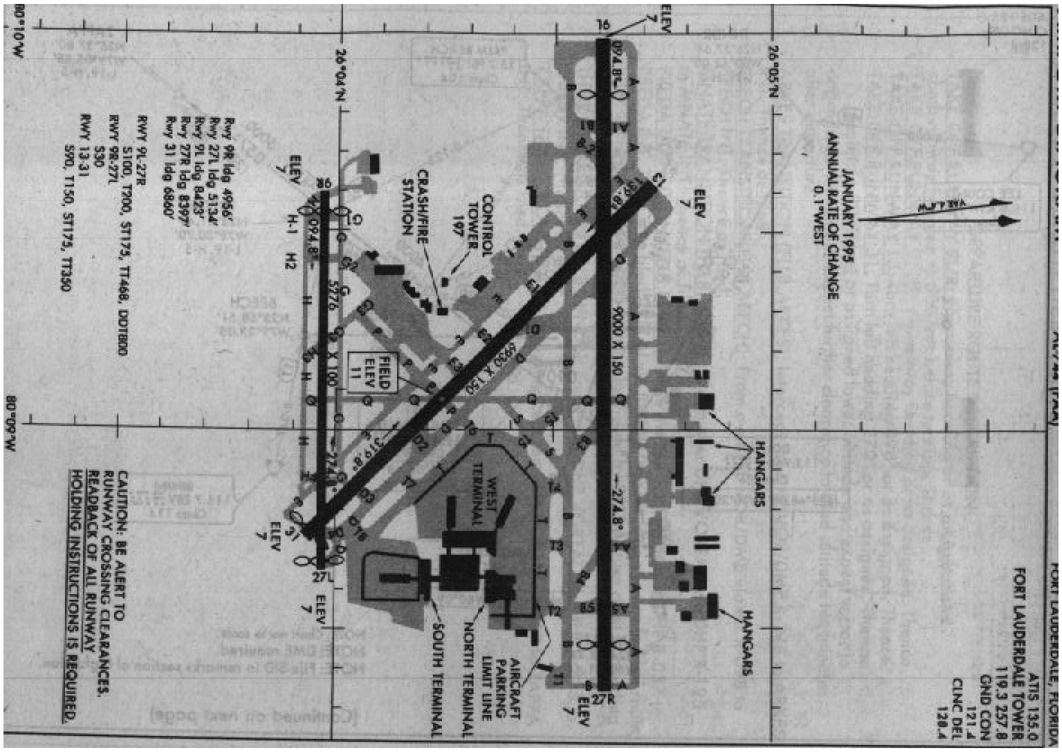

Fort Bliss Military Res
Homestead Meadows

NEWARK


AIRPORT DIAGRAM
AL-285 (FAA)
ATIS ARR 115.7 134.825
DEP 132.45
NEWARK TOWER
118.3 257.6
GND CON
121.8
CLNC DEL
118.85
Rwy 29 ldg 6502'
Rwy 4L ldg 7460'
Rwy 22R ldg 9560'
Rwy 4R ldg 8790'
Rwy 22L ldg 8210'
GENERAL AVIATION PARKING
TERMINAL A
TERMINAL B
TERMINAL C
CONTROL TOWER
UPS CARGO
FEDEX CARGO
FIELD ELEV 18
6800 X 150
10000 X 150
9980 X 150
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES. READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
JANUARY 1995
ANNUAL RATE OF CHANGE
0.1° W
NEWARK, NEW JERSEY
NEWARK INTL (EWR)

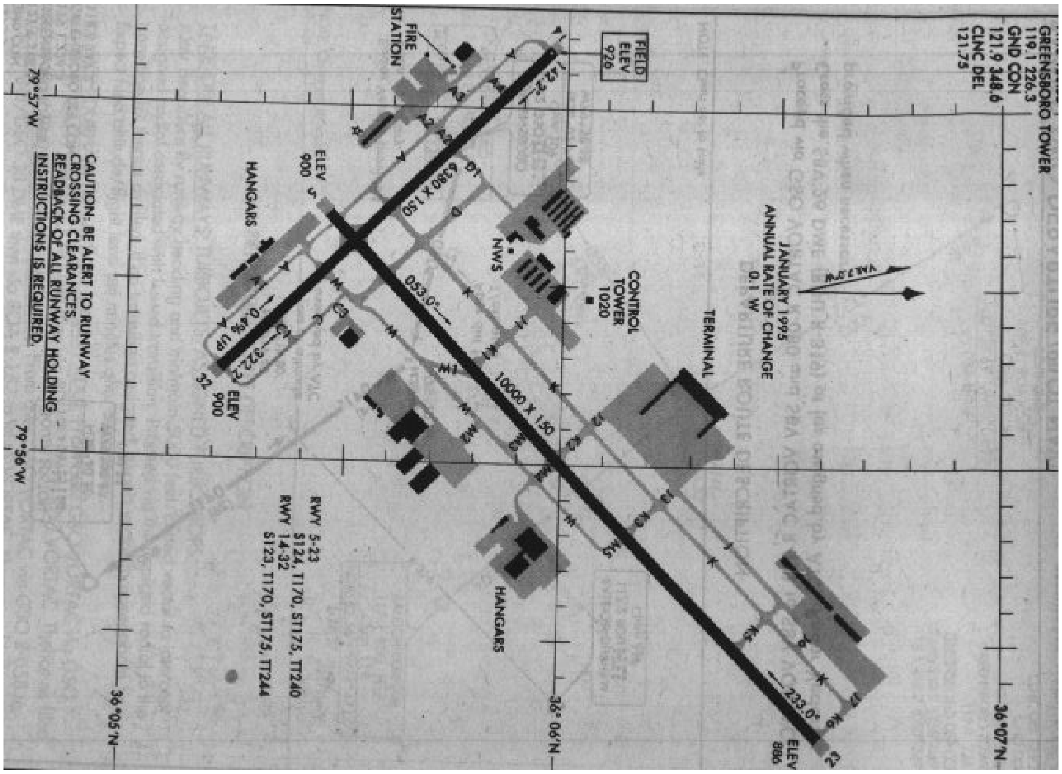

South Orange
Newark
Kearny
Jersey City
Elizabeth
Bayonne

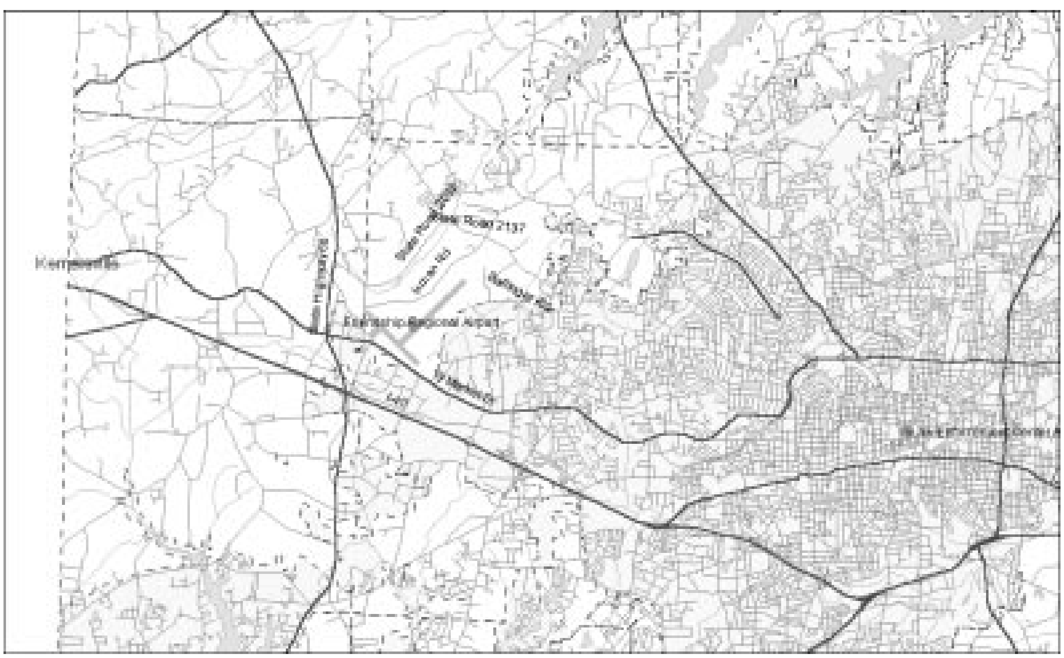
FORT LAUDERDALE



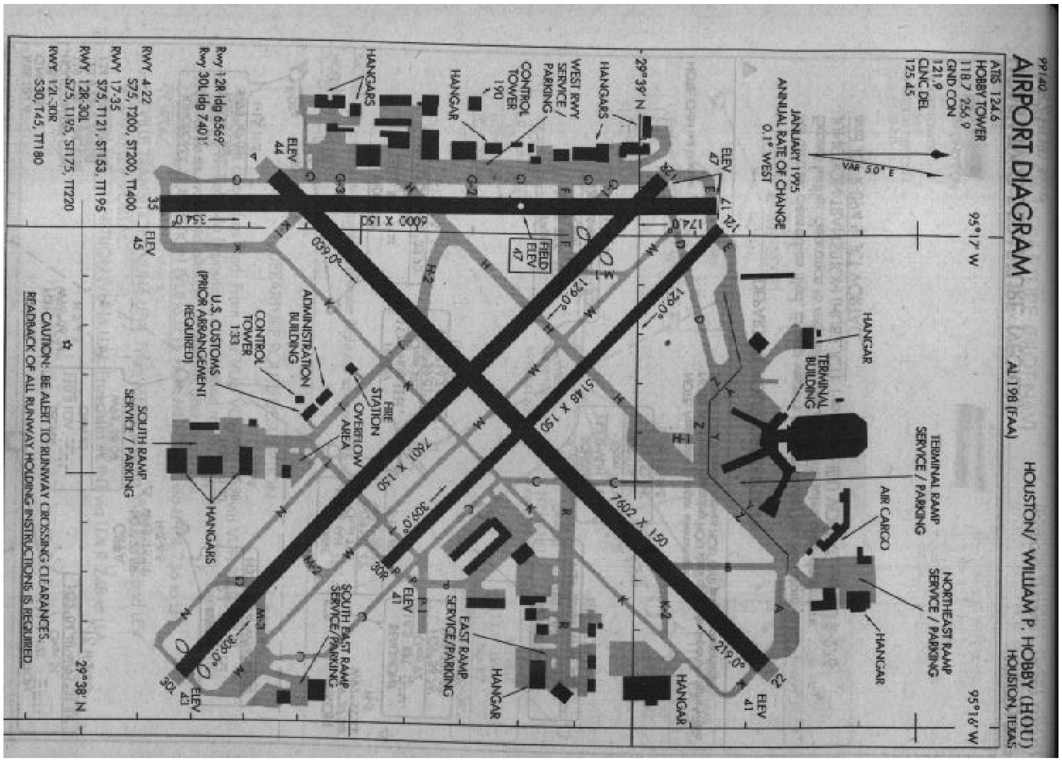
FORT LAUDERDALE

GREENSBORO

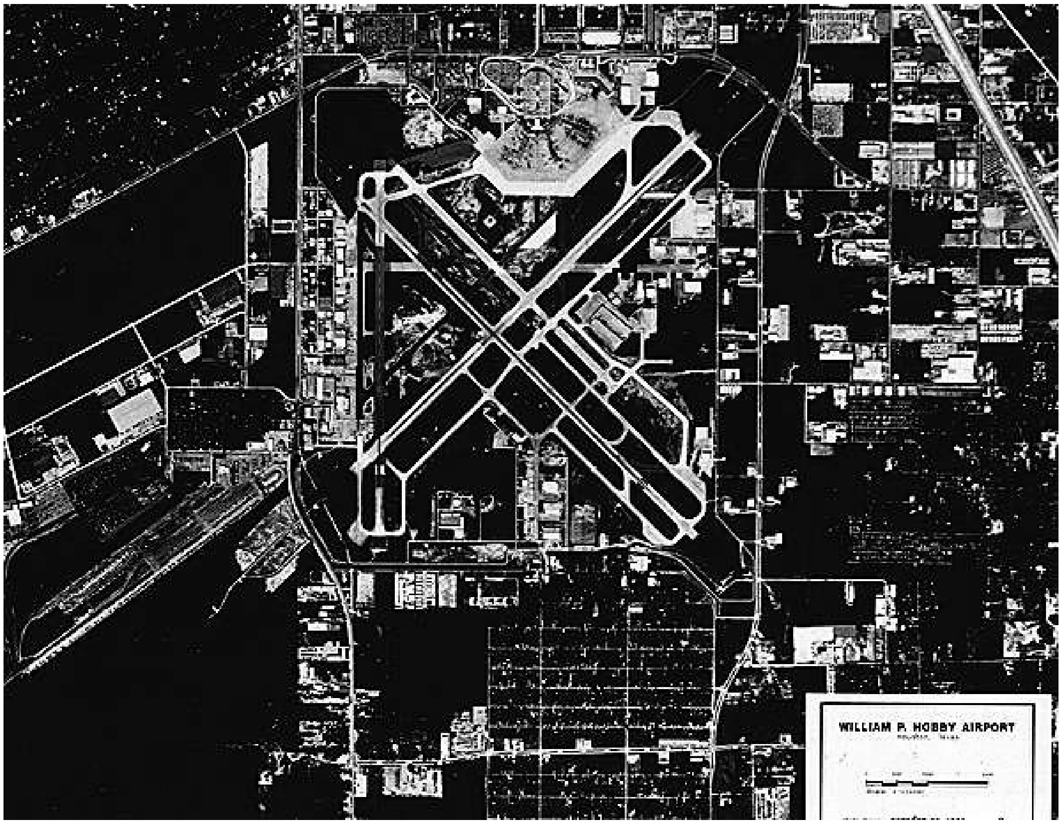

GREENSBORO TOWER
119.1 226.3
GND CON
121.9 348.6
CLNC DEL
121.75
FIELD ELEV 926
FIRE STATION
JANUARY 1995
ANNUAL RATE OF CHANGE
0.1 W
TERMINAL
CONTROL TOWER 1020
NWS
HANGARS
HANGARS
10000 X 150
6380 X 150
053.0°
233.0°
142.2°
322.2°
0.4% UP
ELEV 900
ELEV 900
ELEV 886
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES. READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
RWY 5-23
S124, T170, ST175, TT240
RWY 14-32
S123, T170, ST175, TT244
79°57'W
79°56'W
36°05'N
36°06'N
36°07'N



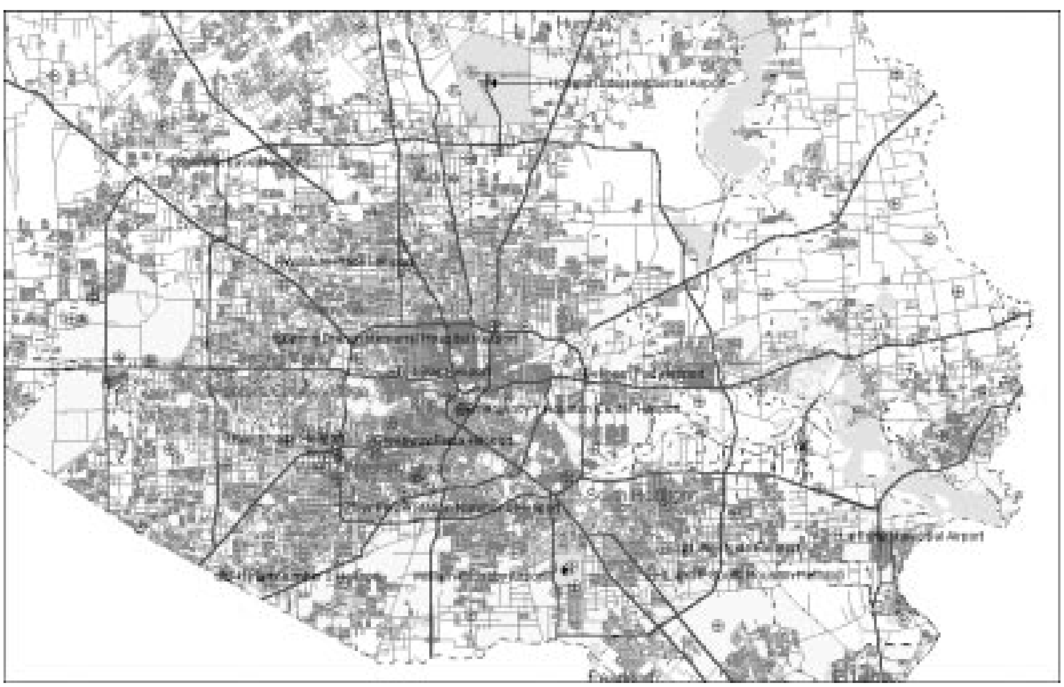
HOUSTON HOBBY



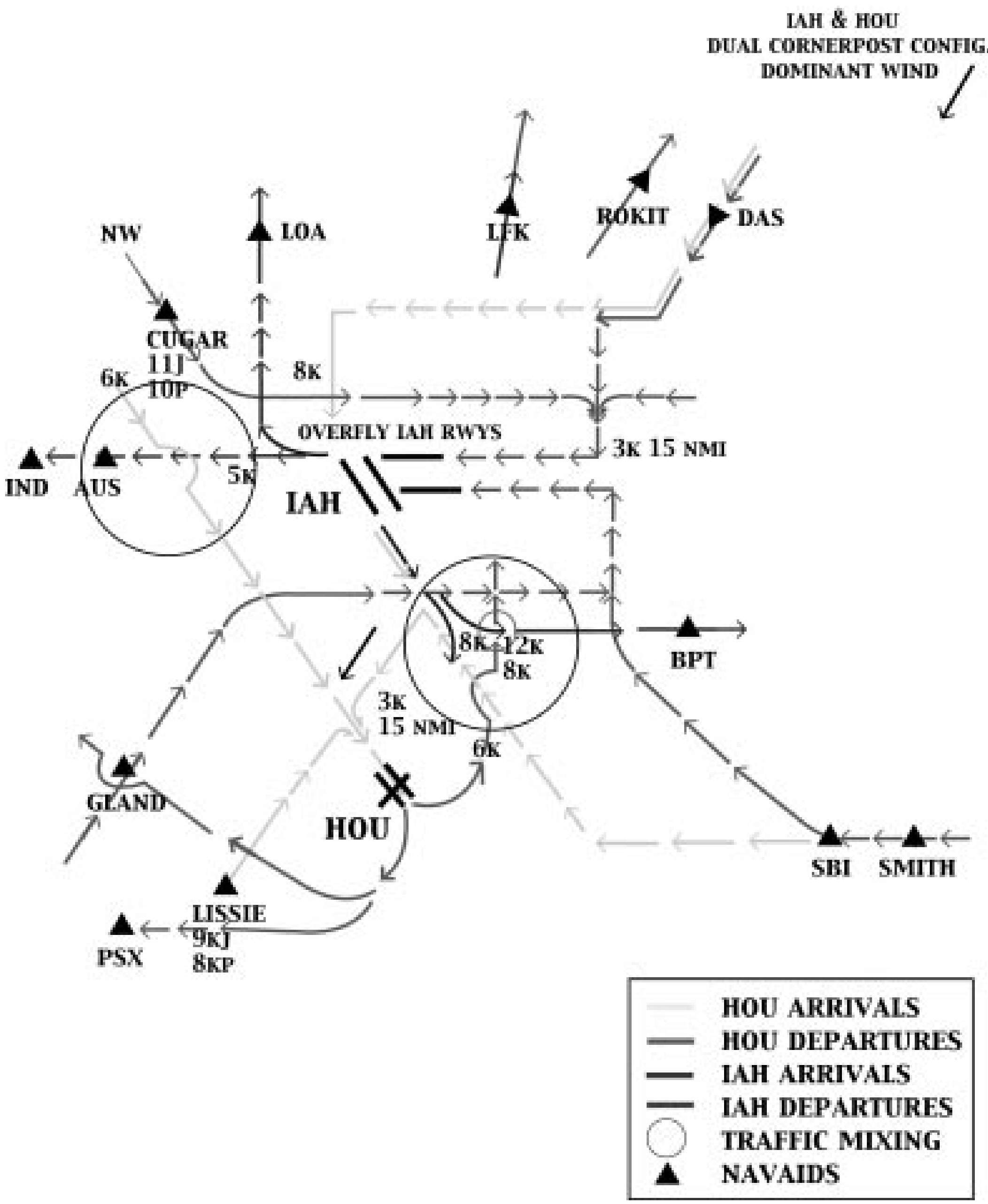
HOUSTON HOBBY CONTINUED: AERIAL PHOTO



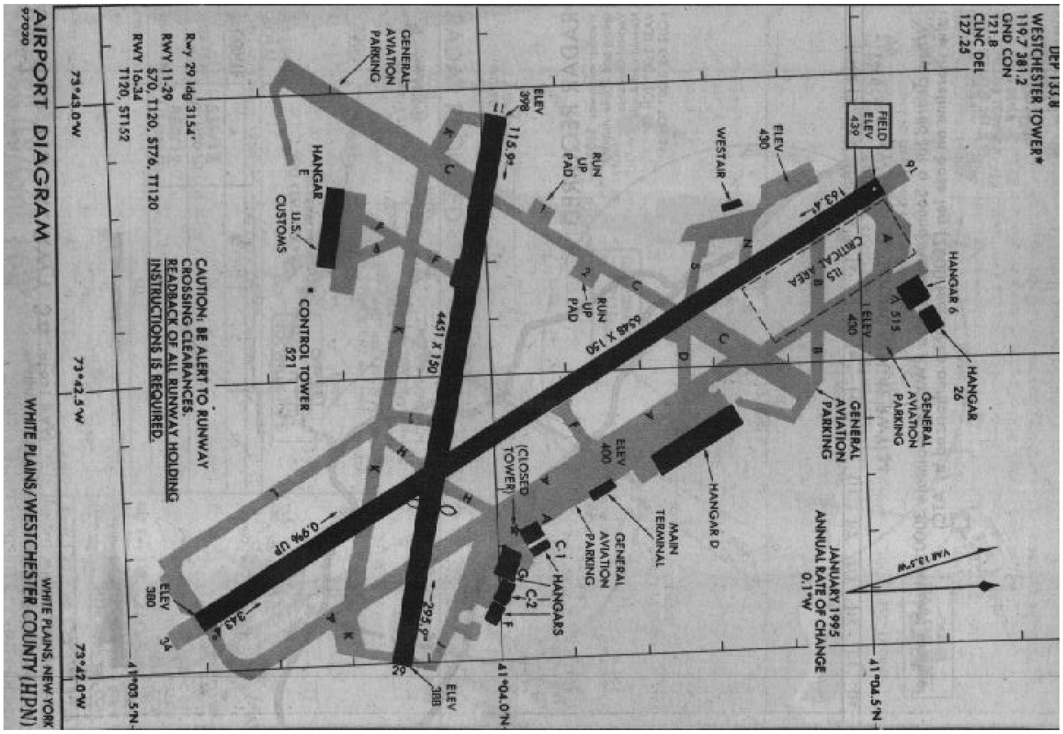
HOUSTON HOBBY AND INTERCONTINENTAL/BUSH



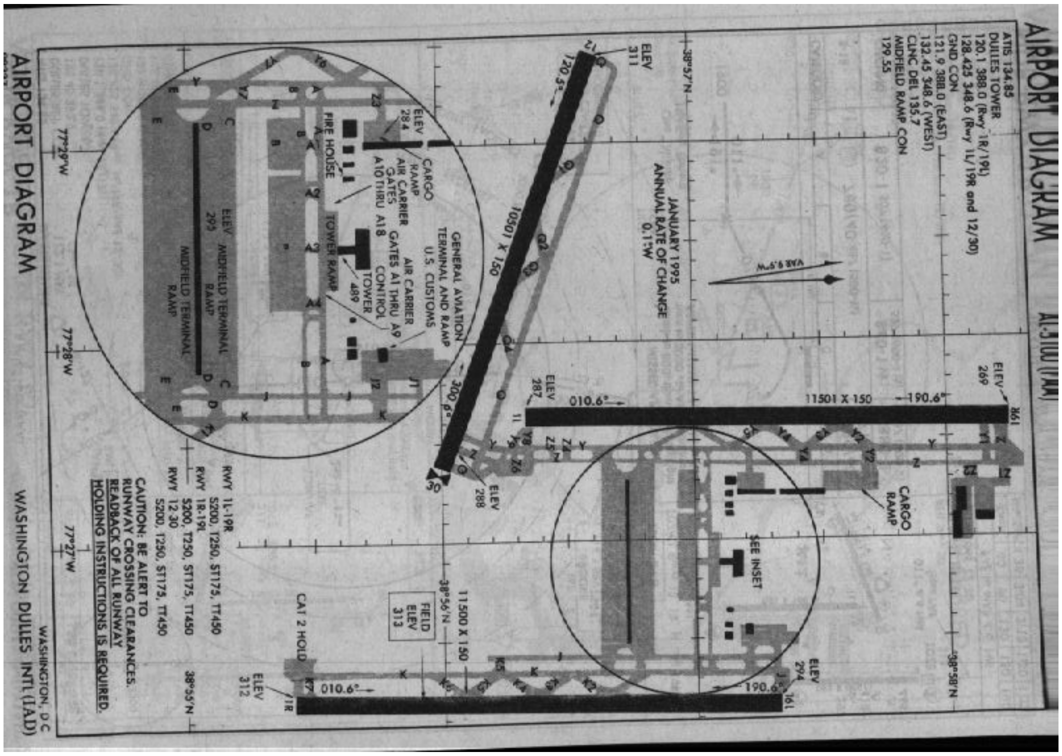
HOUSTON HOBBY AND INTERCONTINENTAL/BUSH AIRSPACE FLOWS



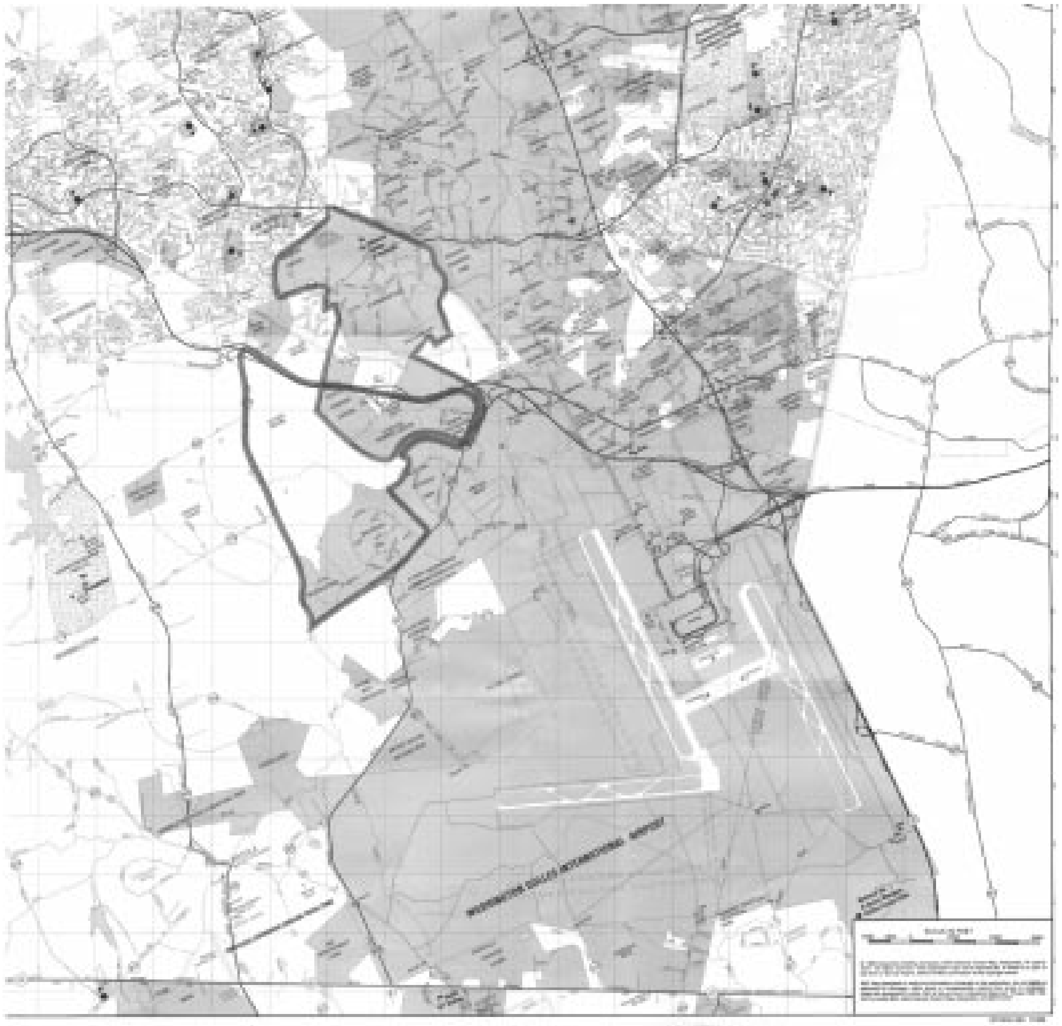
WHITE PLAINS/WESTCHESTER COUNTY



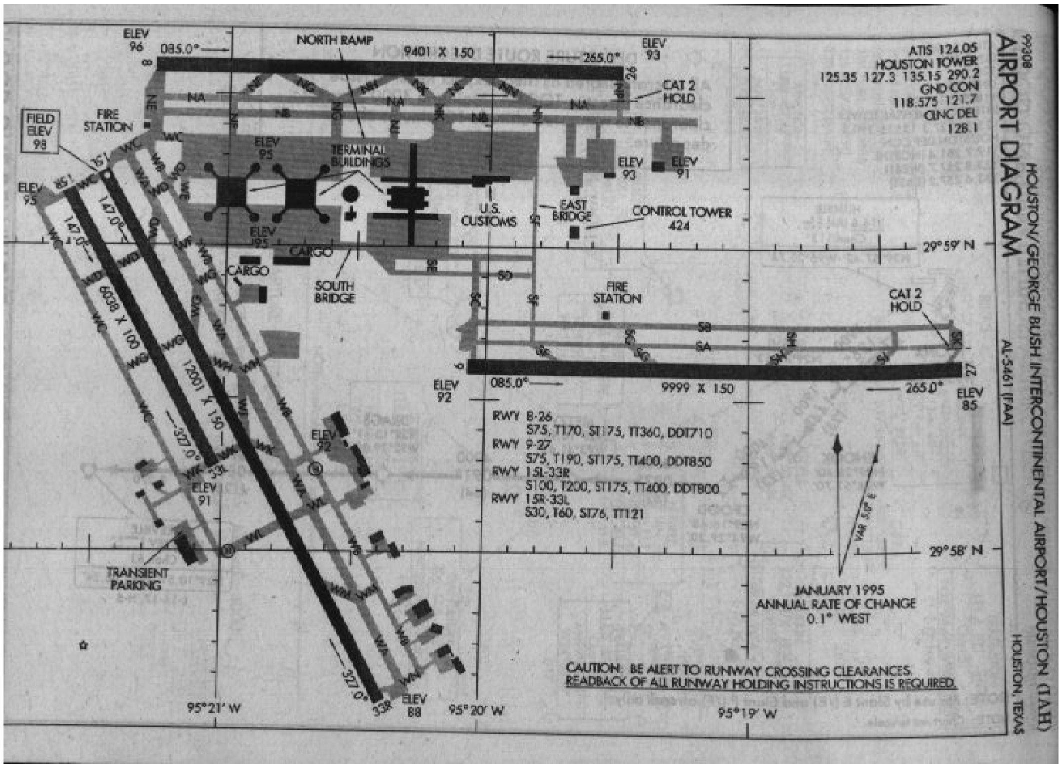
WASHINGTON DULLES

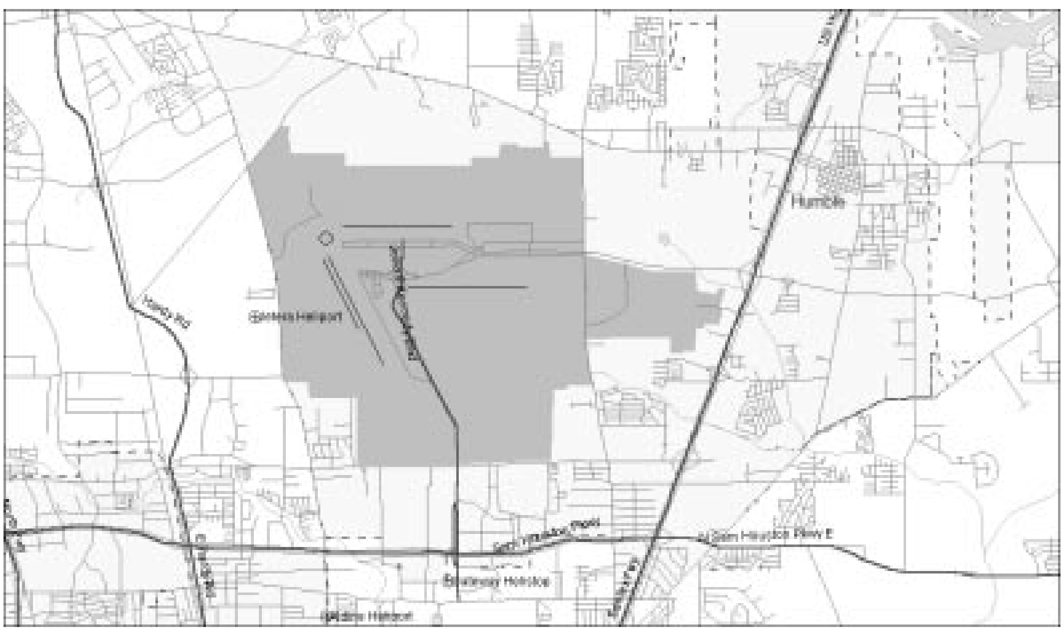


WASHINGTON DULLES

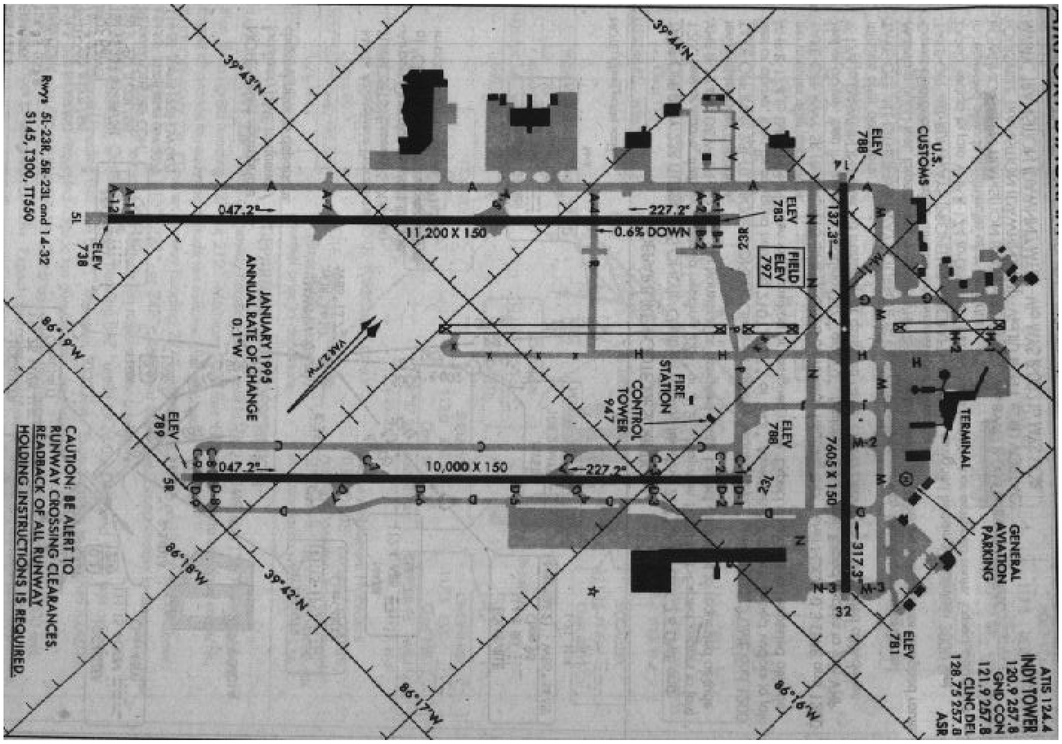


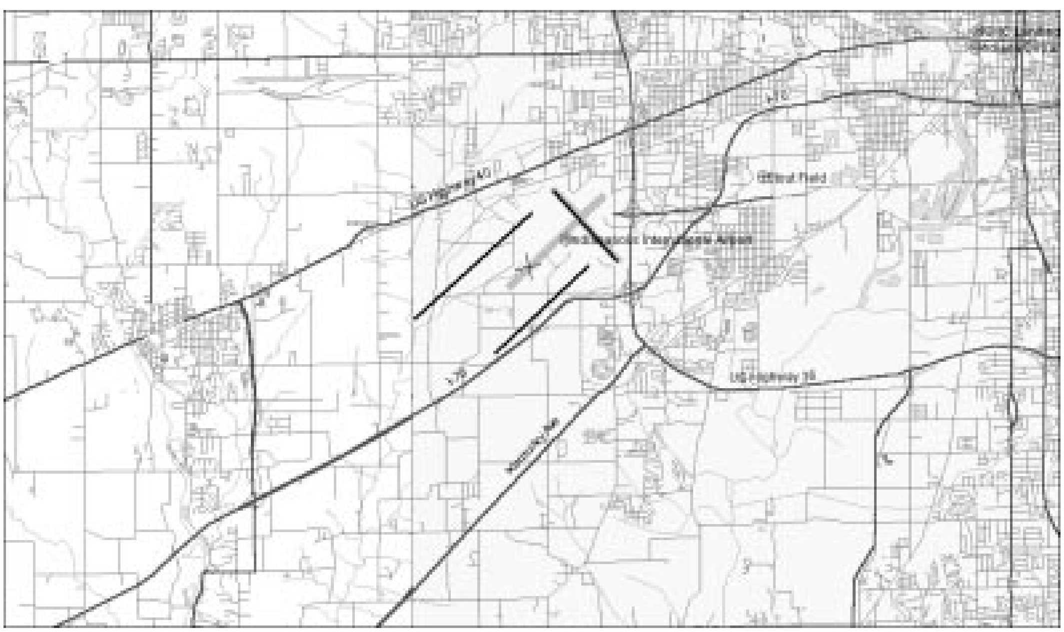
HOUSTON GEORGE BUSH / INTERCONTINENTAL





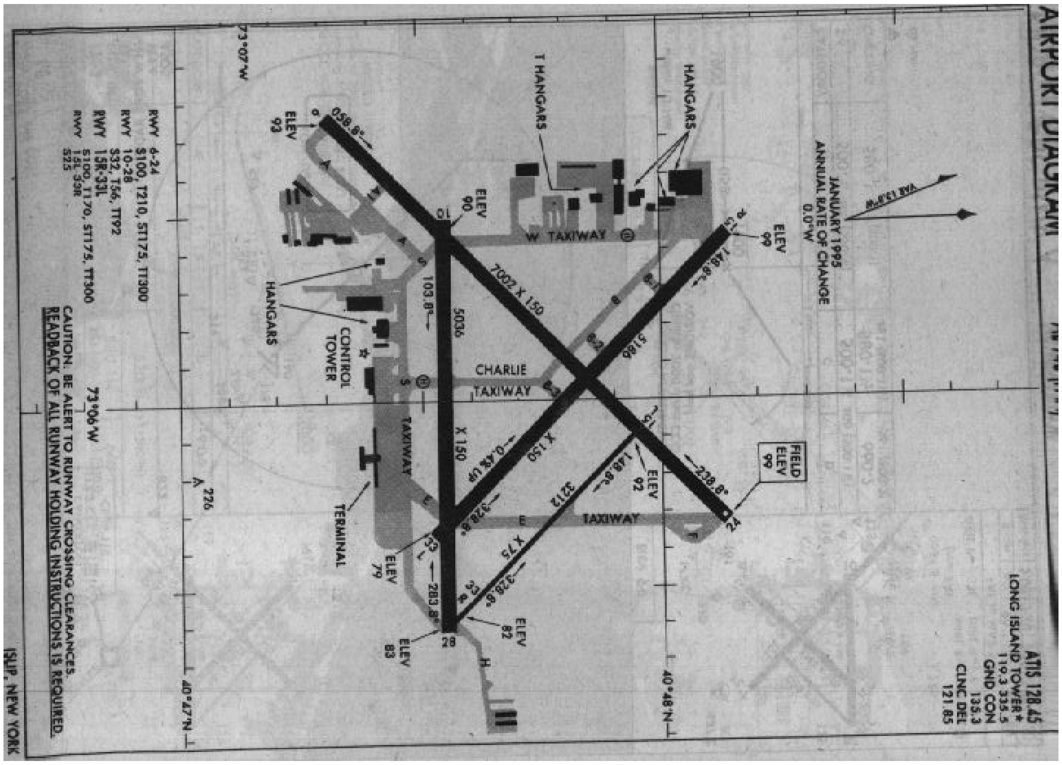
INDIANAPOLIS

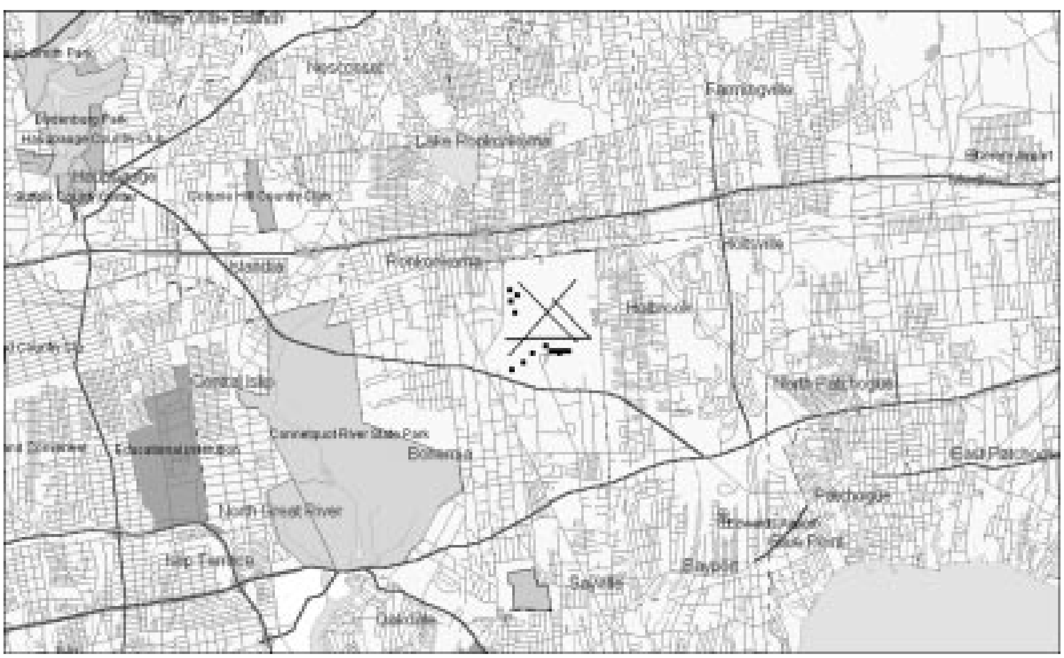




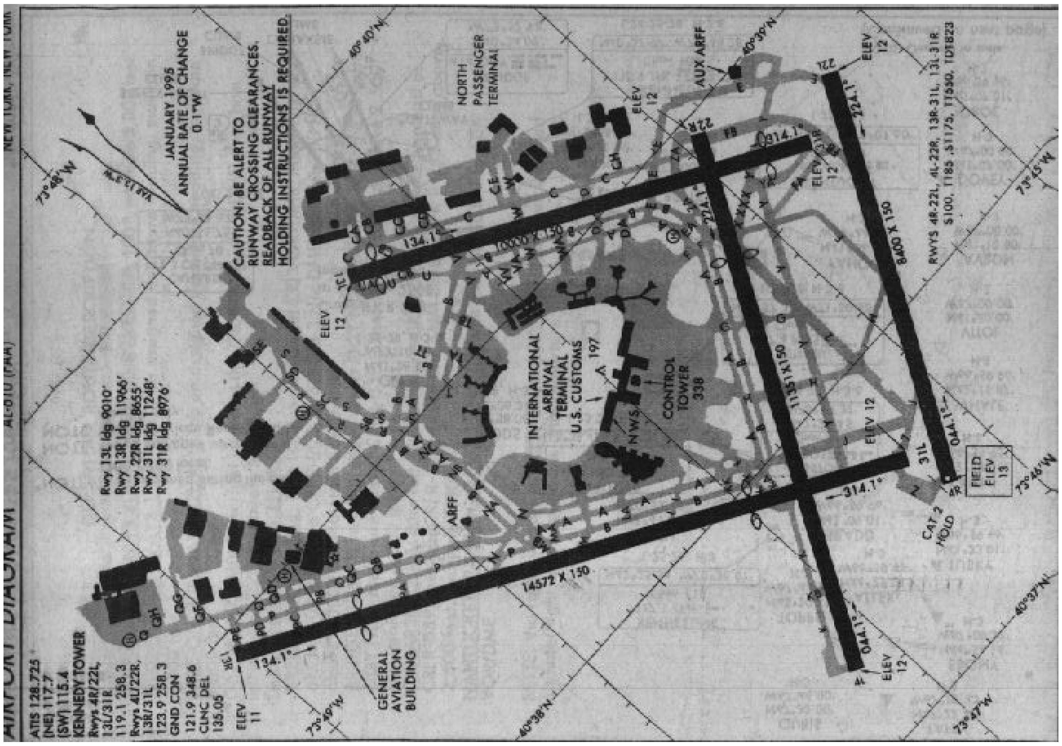
INDIANAPOLIS

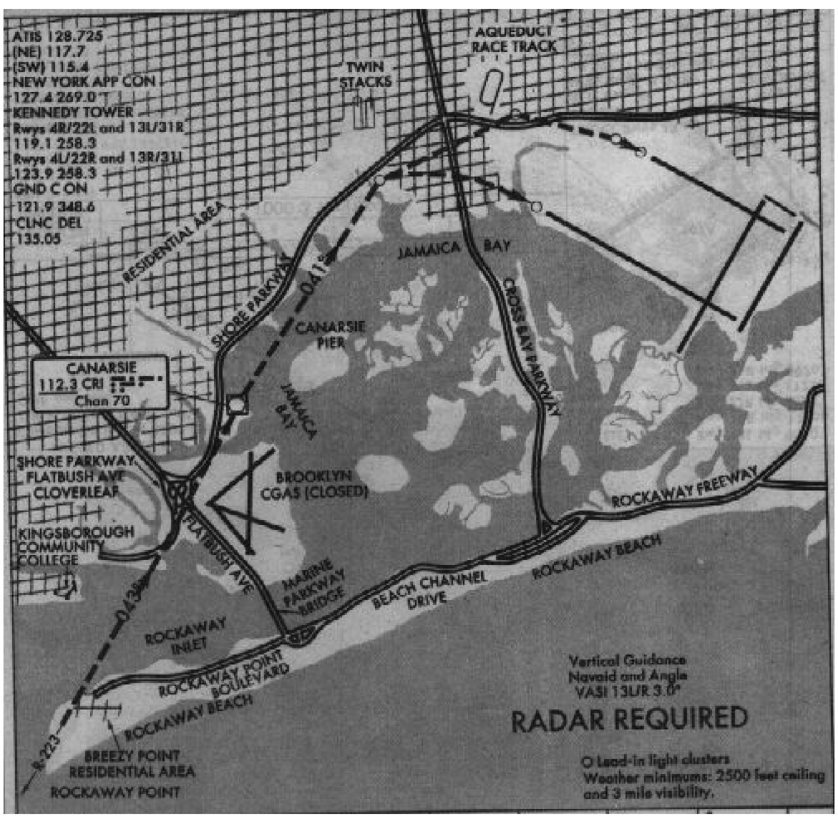
ISLIP


AIRPORT DIAGRAM
JANUARY 1995
ANNUAL RATE OF CHANGE
0.0°W
HANGARS
T HANGARS
W TAXIWAY
CHARLIE
TAXIWAY
TAXIWAY
CONTROL
TOWER
TERMINAL
FIELD
ELEV
99
7002 X 150
5036
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES.
READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
ISLIP, NEW YORK


Nesconset
Farmingville
Lake Ronkonkoma
Ronkonkoma
Holtsville
Holbrook
Central Islip
North Patchogue
Connetquot River State Park
Bohemia
East Patchogue
Patchogue
North Great River
Islip Terrace
Sayville
Bayport
Oakdale

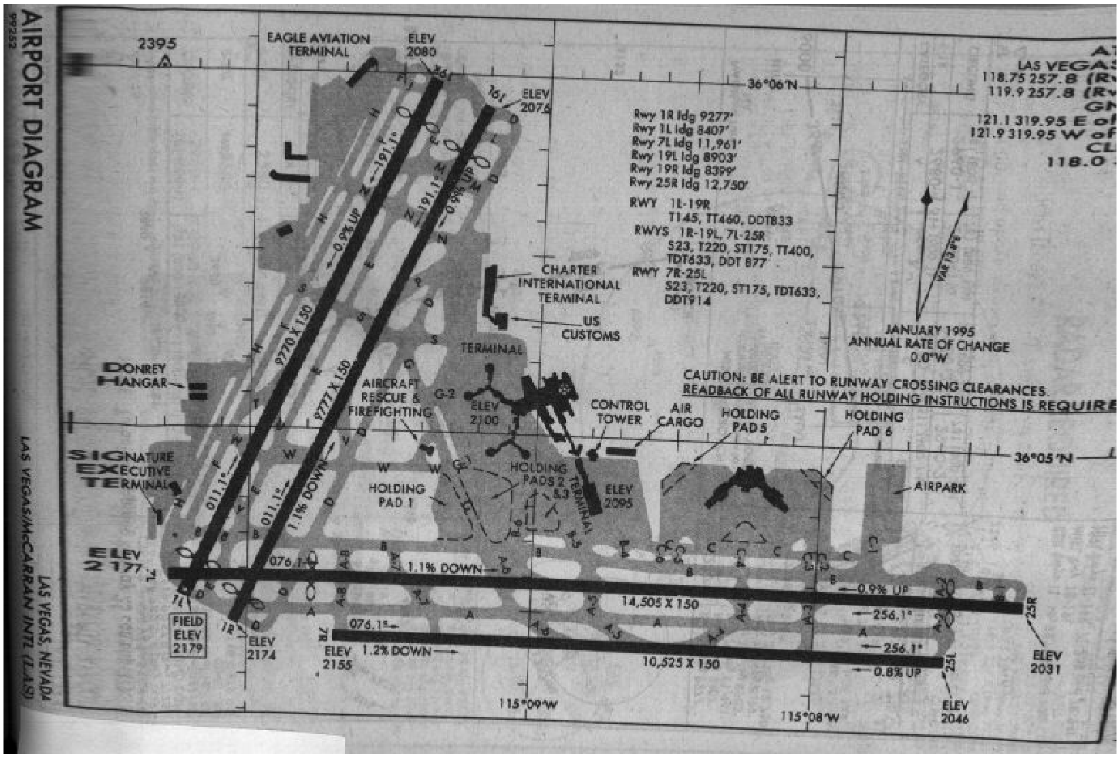
NEW YORK - JOHN F. KENNEDY INTERNATIONAL

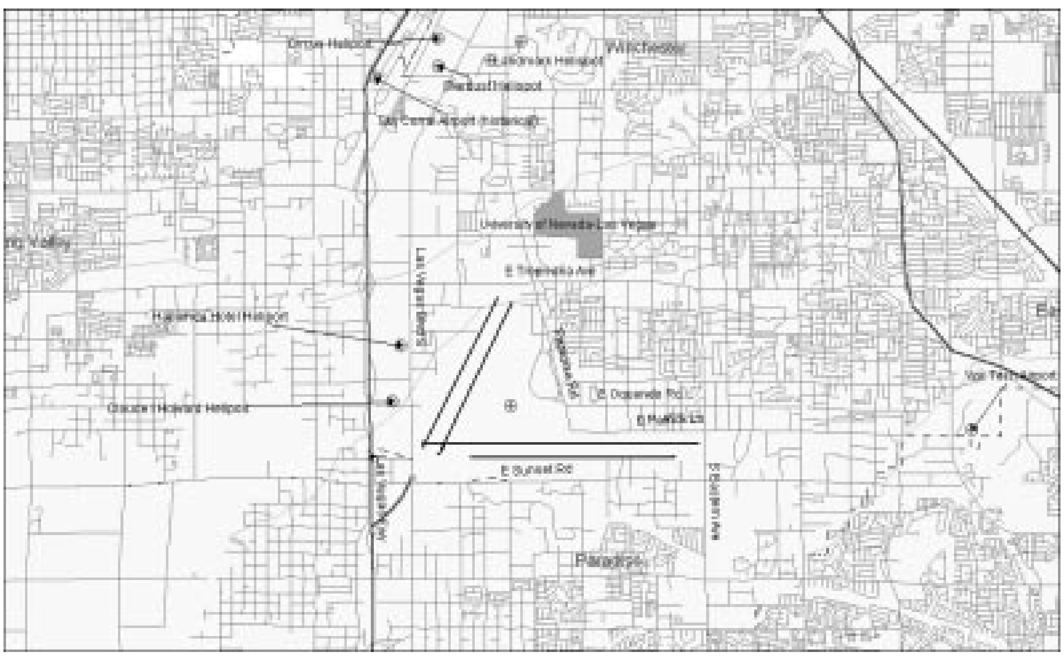




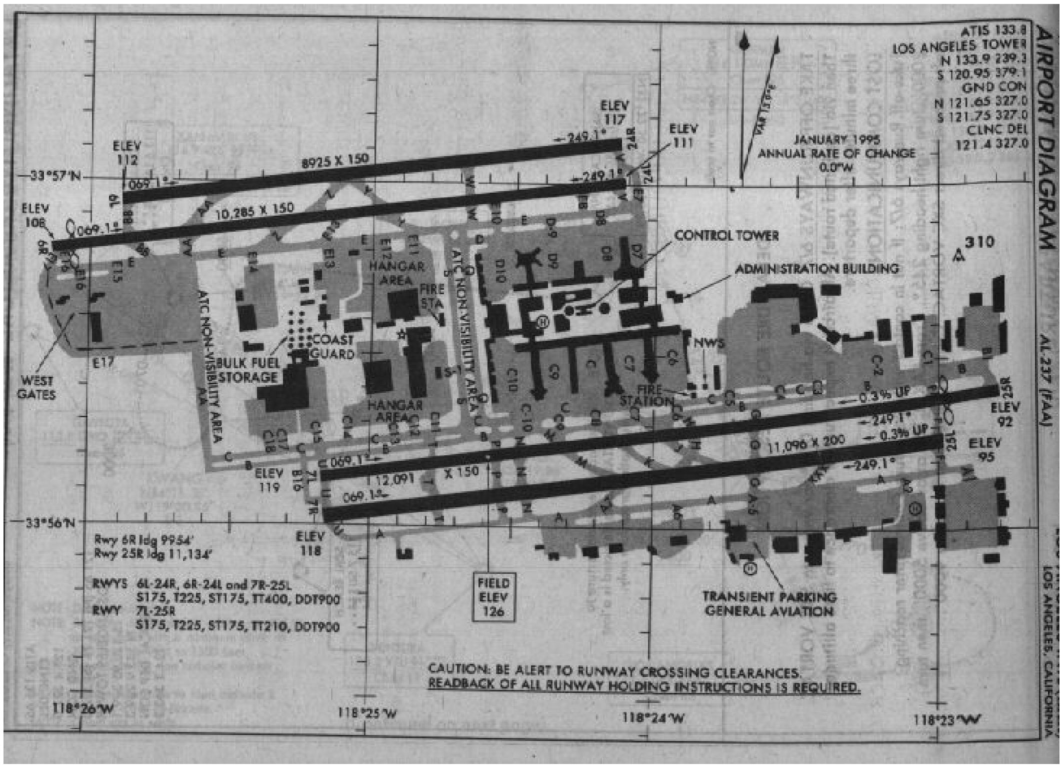
NEW YORK - JOHN F. KENNEDY INTERNATIONAL

LAS VEGAS

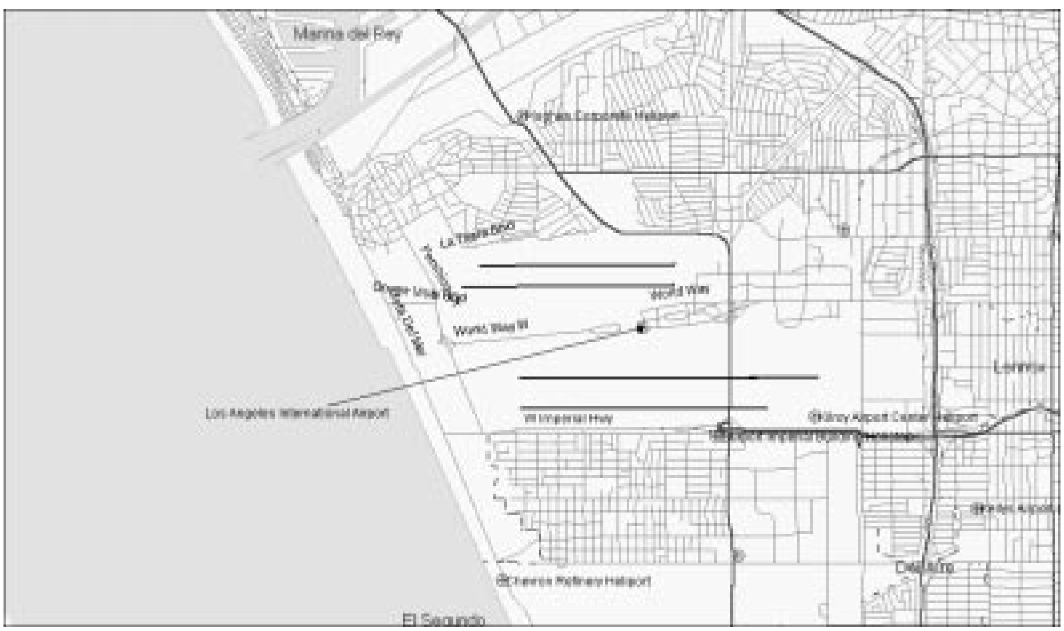




LOS ANGELES



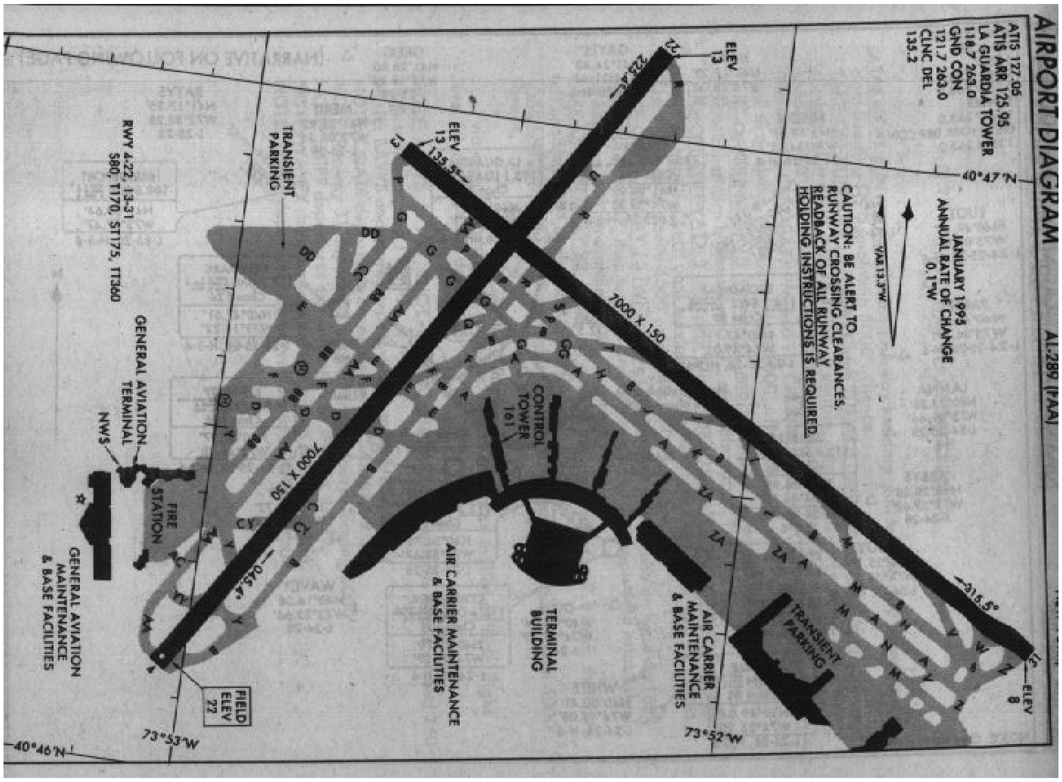
ATIS 133.8
LOS ANGELES TOWER
N 133.9 239.3
S 120.95 379.1
GND CON
N 121.65 327.0
S 121.75 327.0
CLNC DEL
121.4 327.0
AIRPORT DIAGRAM
AL-237 (FAA)
LOS ANGELES, CALIFORNIA
JANUARY 1995
ANNUAL RATE OF CHANGE
0.0°W
CONTROL TOWER
ADMINISTRATION BUILDING
HANGAR AREA
FIRE STA
COAST GUARD
BULK FUEL STORAGE
WEST GATES
ATC NON-VISIBILITY AREA
FIRE STATION
NWS
8925 X 150
10,285 X 150
11,096 X 200
12,091 X 150
Rwy 6R ldg 9954'
Rwy 25R ldg 11,134'
RWYS 6L-24R, 6R-24L and 7R-25L
S175, T225, ST175, TT400, DDT900
RWY 7L-25R
S175, T225, ST175, TT210, DDT900
FIELD ELEV 126
TRANSIENT PARKING
GENERAL AVIATION
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES.
READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
33°57'N
33°56'N
118°26'W
118°25'W
118°24'W
118°23'W

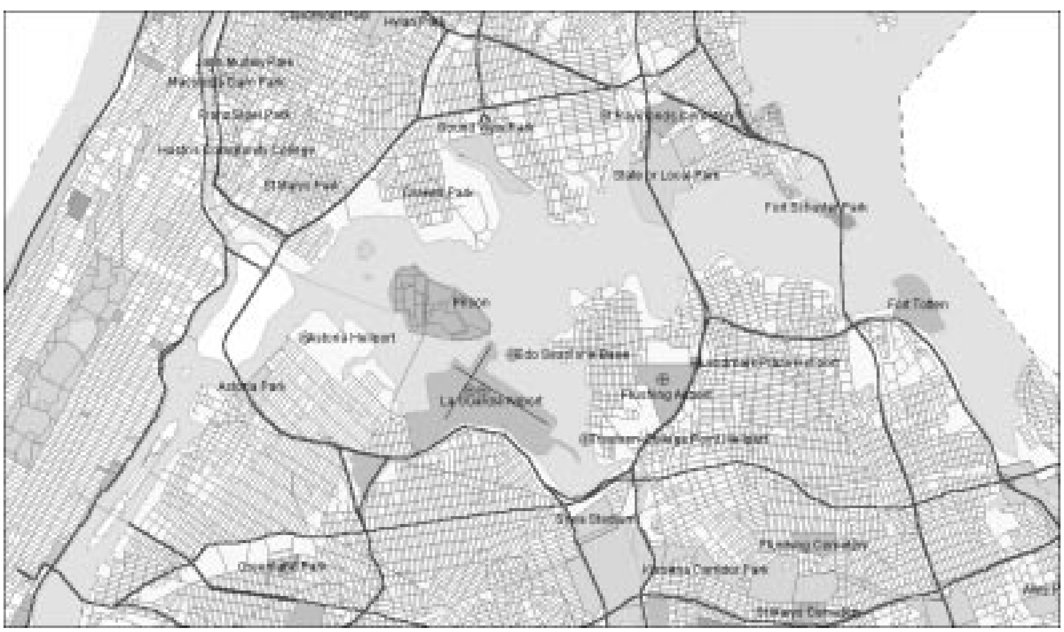


Marina del Rey
Los Angeles International Airport
W Imperial Hwy
El Segundo

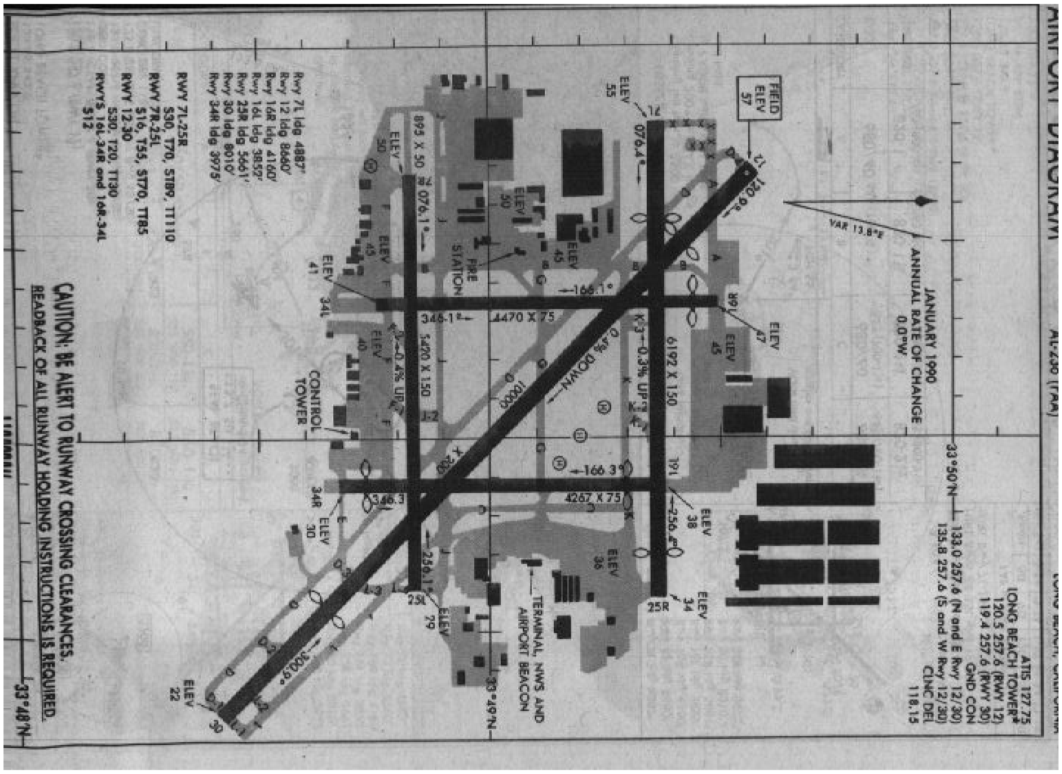
LOS ANGELES

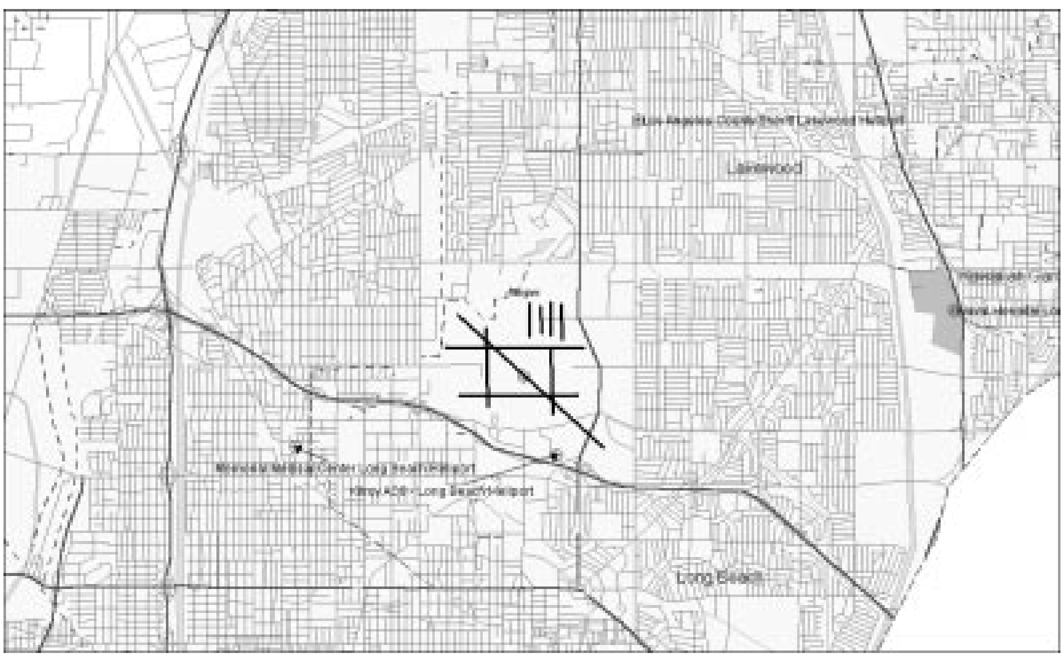
NEW YORK - LAGUARDIA





LONG BEACH

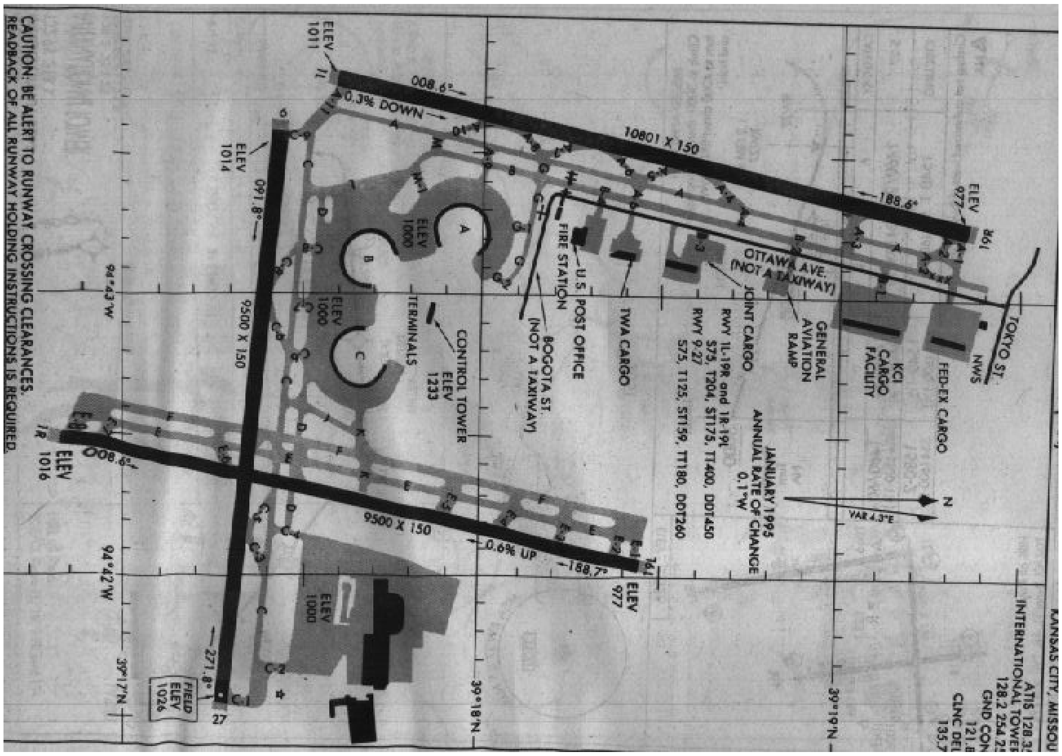


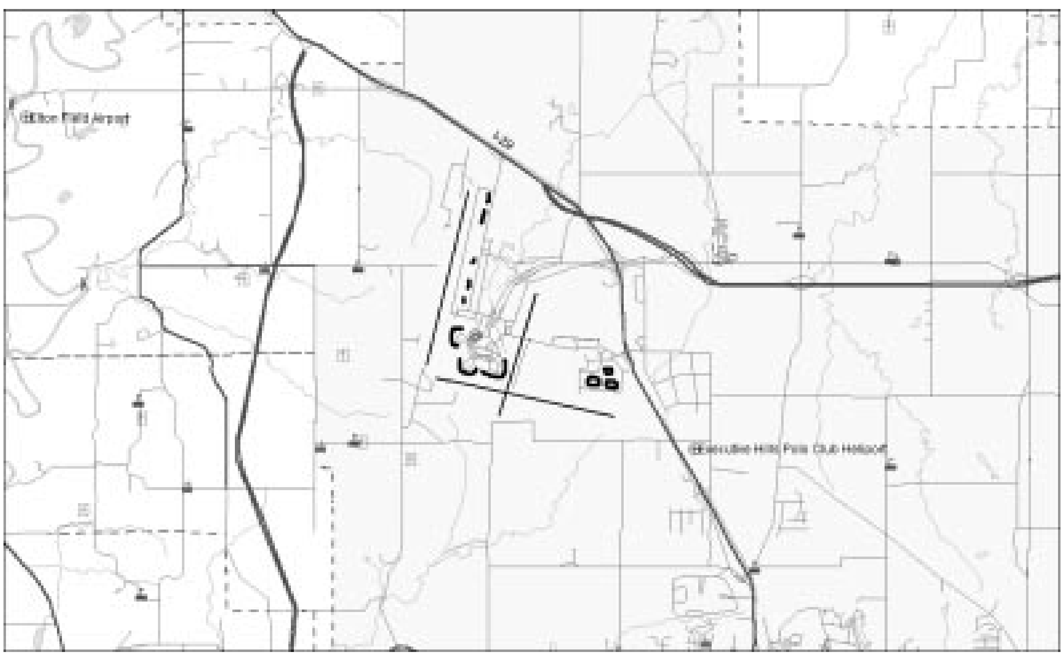


LONG BEACH, CONTINUED

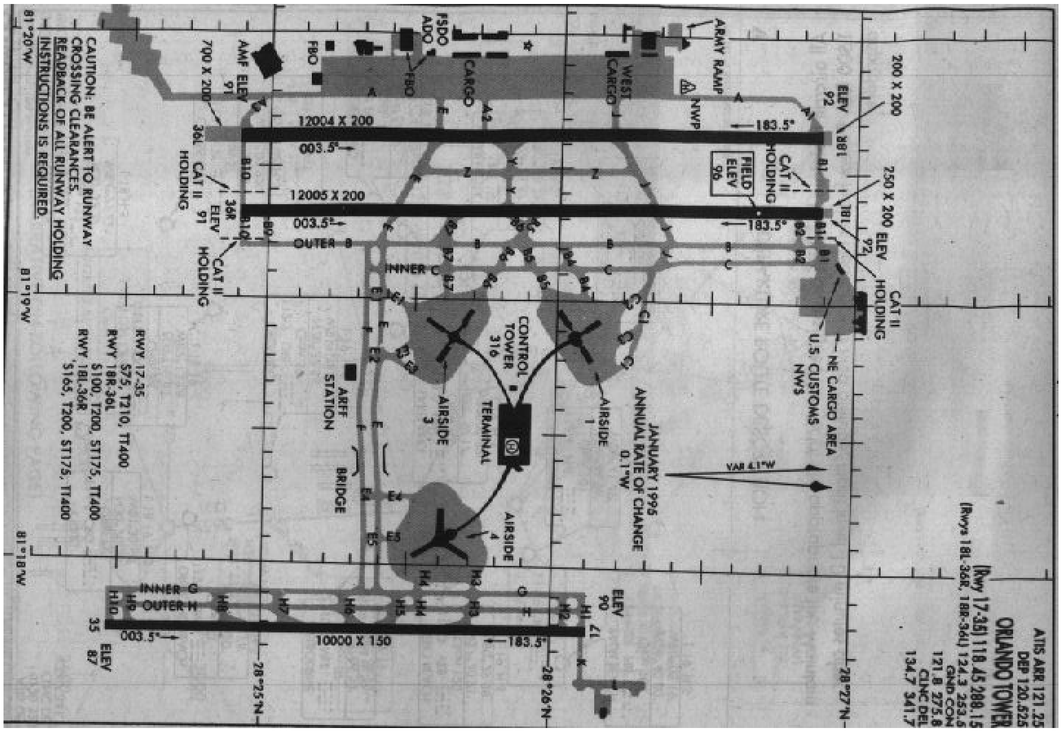
KANSAS CITY

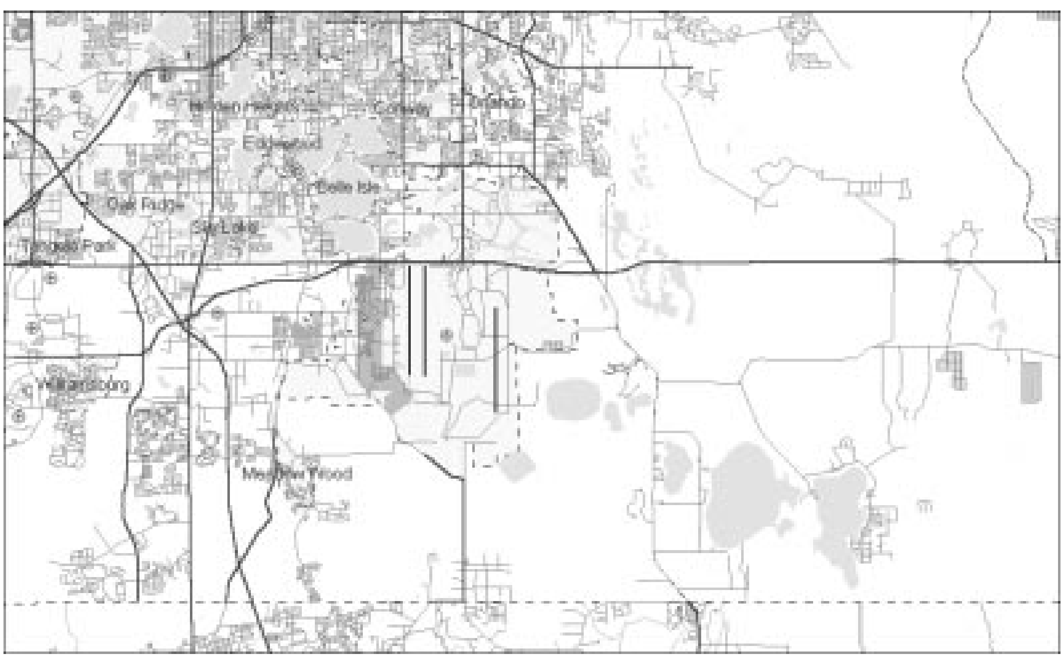
KANSAS CITY


CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES. READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
10801 X 150
9500 X 150
0.3% DOWN
0.6% UP
U.S. POST OFFICE
FIRE STATION
TWA CARGO
JOINT CARGO
GENERAL AVIATION RAMP
KCI CARGO FACILITY
FED-EX CARGO
NWS
TOKYO ST.
OTTAWA AVE. (NOT A TAXIWAY)
BOGOTA ST. (NOT A TAXIWAY)
CONTROL TOWER ELEV 1233
TERMINALS
JANUARY 1995 ANNUAL RATE OF CHANGE 0.1°W
FIELD ELEV 1026
KANSAS CITY, MISSOURI

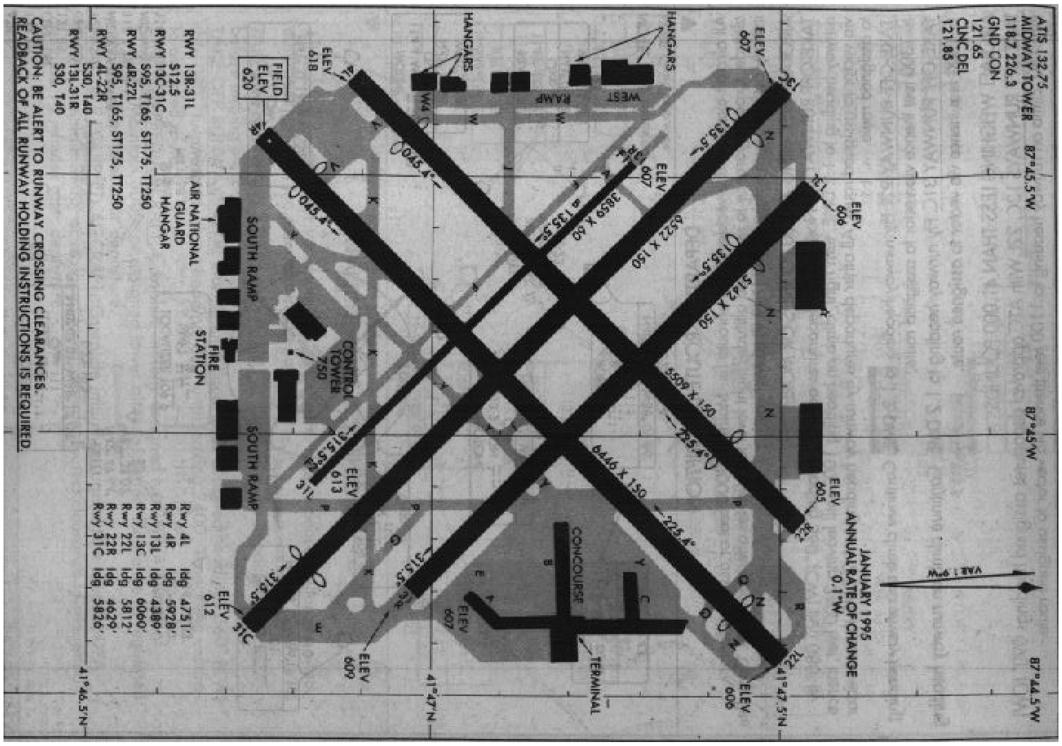

I-29

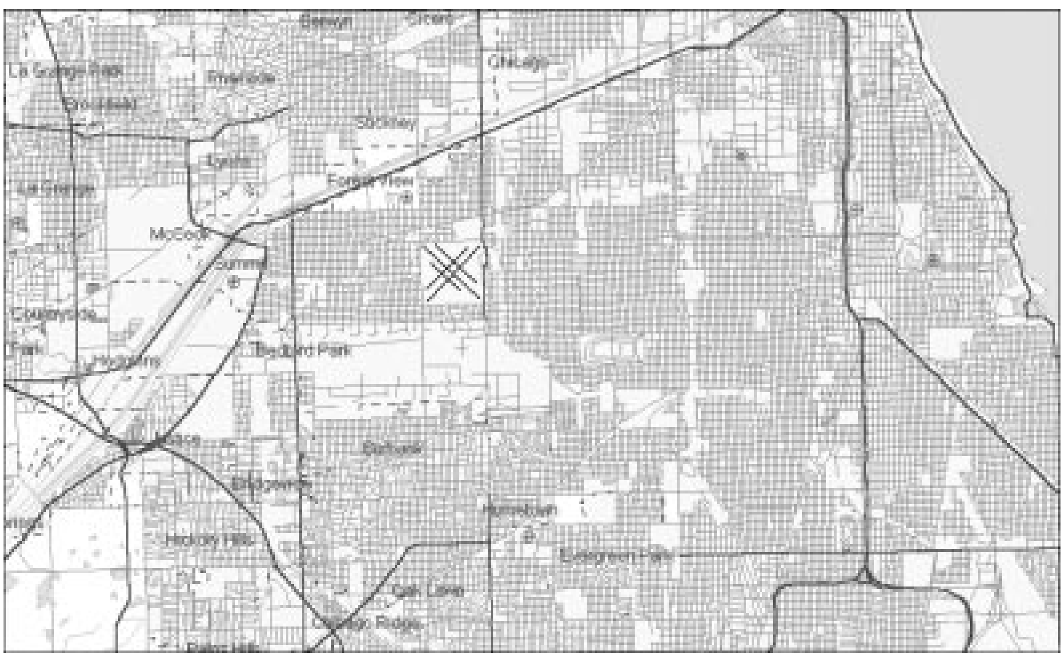
ORLANDO



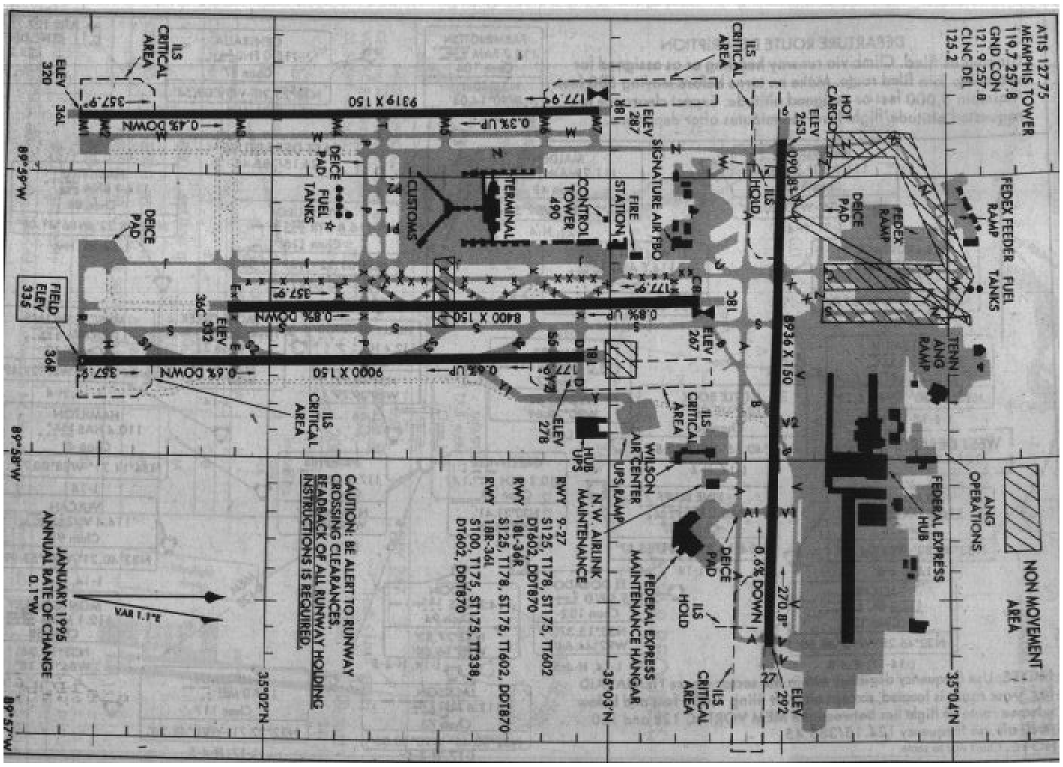


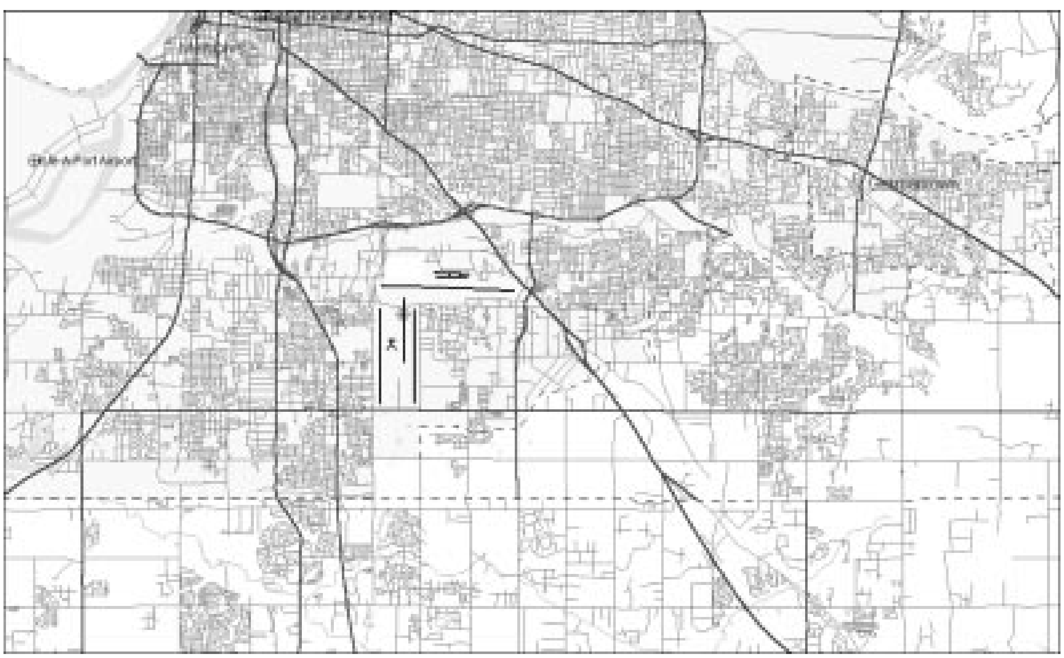
ORLANDO, CONTINUED



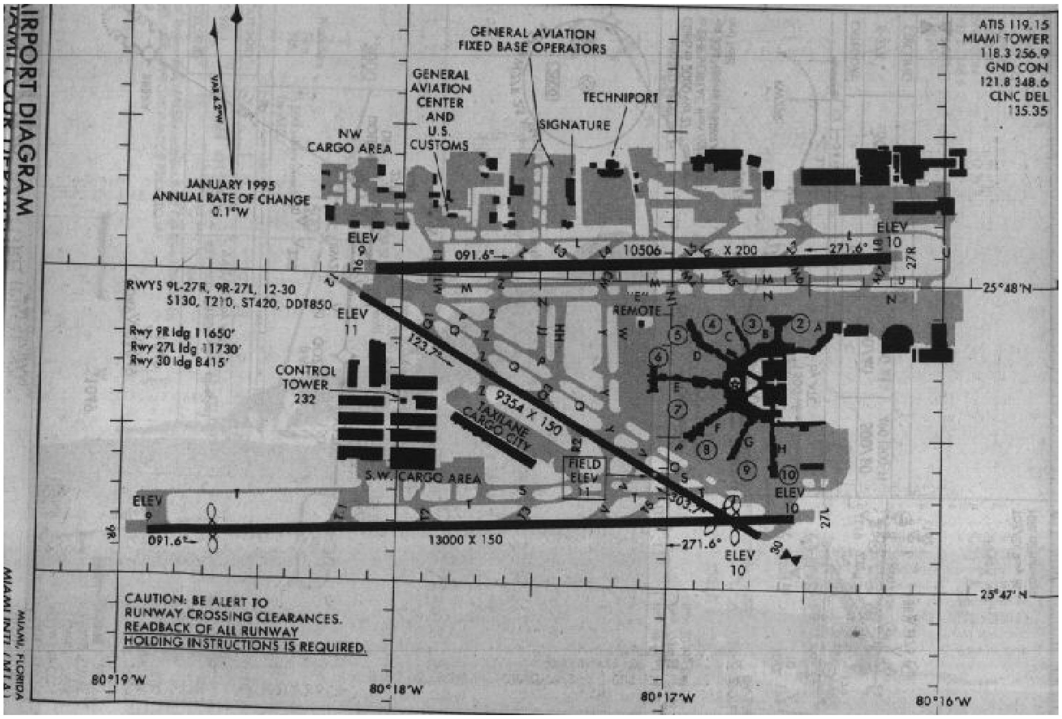


MEMPHIS


ATIS 127.75
MEMPHIS TOWER
119.7 257.8
GND CON
121.9 257.8
CLNC DEL
125.2
FEDEX FEEDER RAMP
FUEL TANKS
FEDEX RAMP
DEICE PAD
HOT CARGO
TENN ANG RAMP
ANG OPERATIONS
NON MOVEMENT AREA
FEDERAL EXPRESS HUB
ILS CRITICAL AREA
ILS HOLD
9319 X 150
8400 X 150
9000 X 150
8936 X 150
CONTROL TOWER 490
TERMINAL
CUSTOMS
FIRE STATION
SIGNATURE AIR FBO
FUEL TANKS
DEICE PAD
FIELD ELEV 335
HUB UPS
WILSON AIR CENTER
UPS RAMP
N.W. AIRLINK MAINTENANCE
FEDERAL EXPRESS MAINTENANCE HANGAR
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES. READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
JANUARY 1995
ANNUAL RATE OF CHANGE
0.1°W
VAR 1.1°E
35°02'N
35°03'N
35°04'N
89°59'W
89°58'W
89°57'W



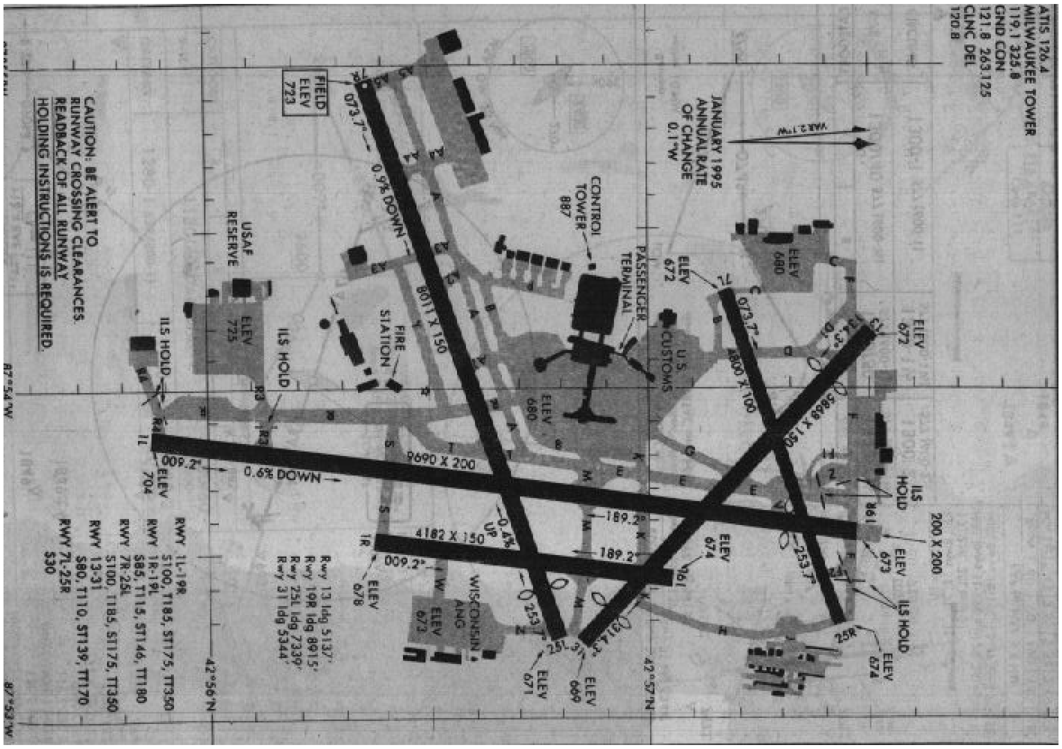
MIAMI

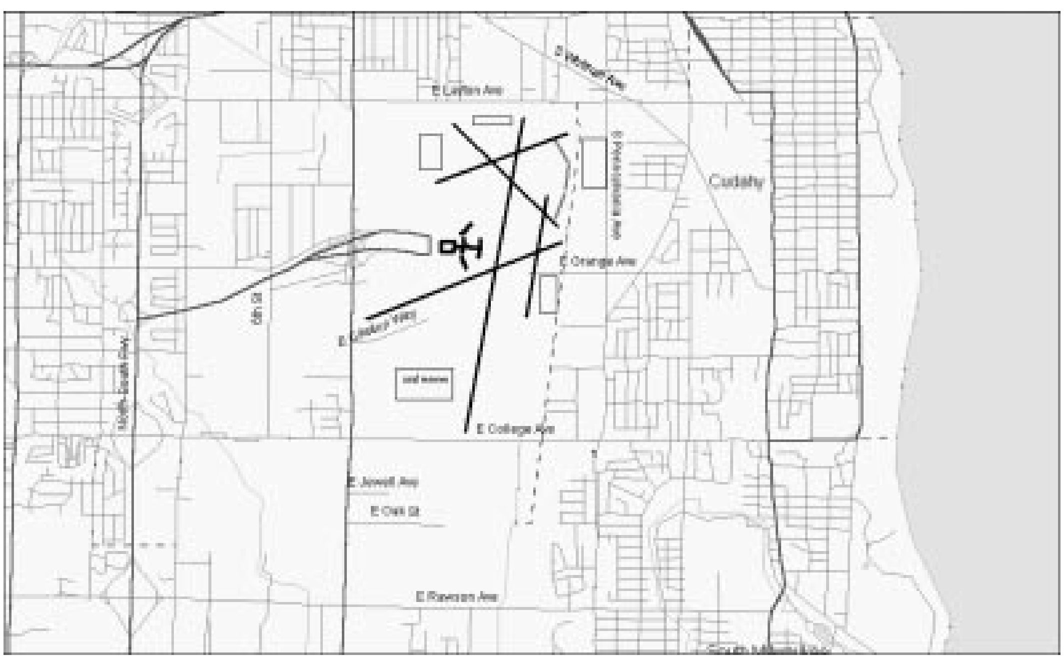


AIRPORT DIAGRAM
GENERAL AVIATION
FIXED BASE OPERATORS
GENERAL AVIATION CENTER AND U.S. CUSTOMS
TECHNIPORT
SIGNATURE
NW CARGO AREA
JANUARY 1995
ANNUAL RATE OF CHANGE
0.1°W
ATIS 119.15
MIAMI TOWER
118.3 256.9
GND CON
121.8 348.6
CLNC DEL
135.35
RWYS 9L-27R, 9R-27L, 12-30
S130, T210, ST420, DDT850
Rwy 9R ldg 11650'
Rwy 27L ldg 11730'
Rwy 30 ldg 8415'
CONTROL TOWER
232
9354 X 150
TAXILANE
CARGO CITY
S.W. CARGO AREA
FIELD ELEV 11
10506 X 200
13000 X 150
CAUTION: BE ALERT TO
RUNWAY CROSSING CLEARANCES.
READBACK OF ALL RUNWAY
HOLDING INSTRUCTIONS IS REQUIRED.
80°19'W
80°18'W
80°17'W
80°16'W
25°48'N
25°47'N
MIAMI, FLORIDA

Doral
Miami Springs
Virginia Gardens
Brownsville
West Miami

MILWAUKEE

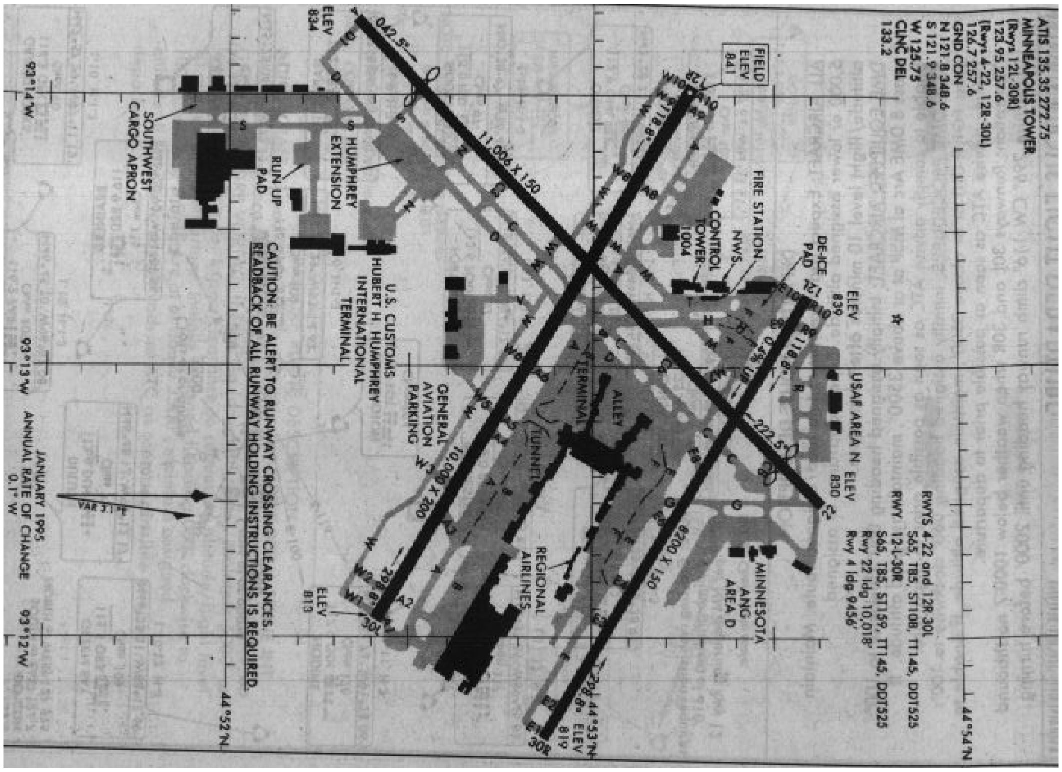


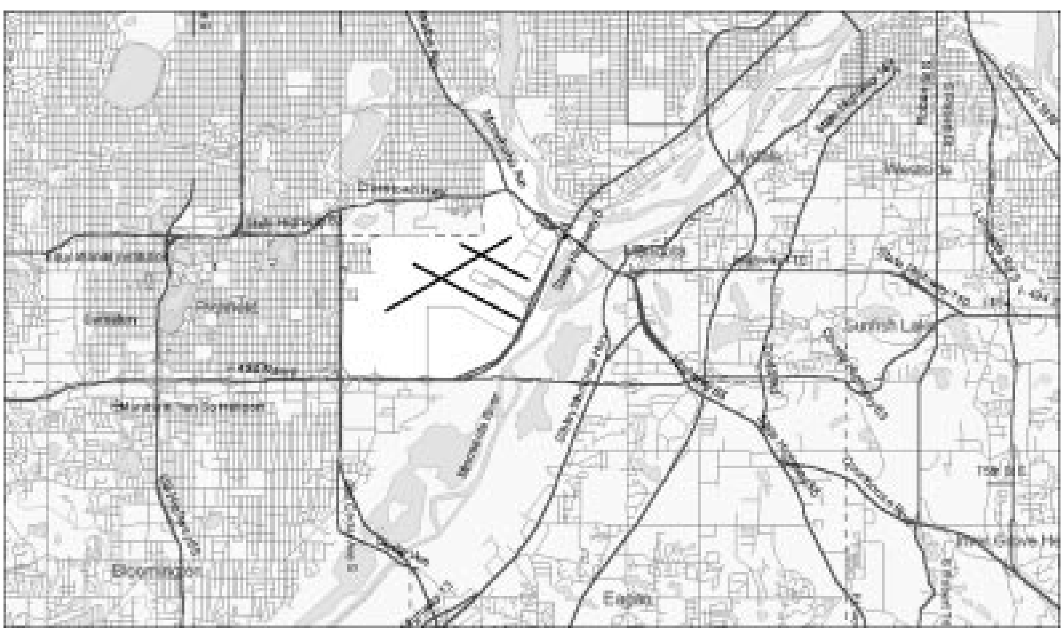


MILWAUKEE AERIAL PHOTOS

MILWAUKEE; IMMEDIATELY EAST OF RUNWAYS

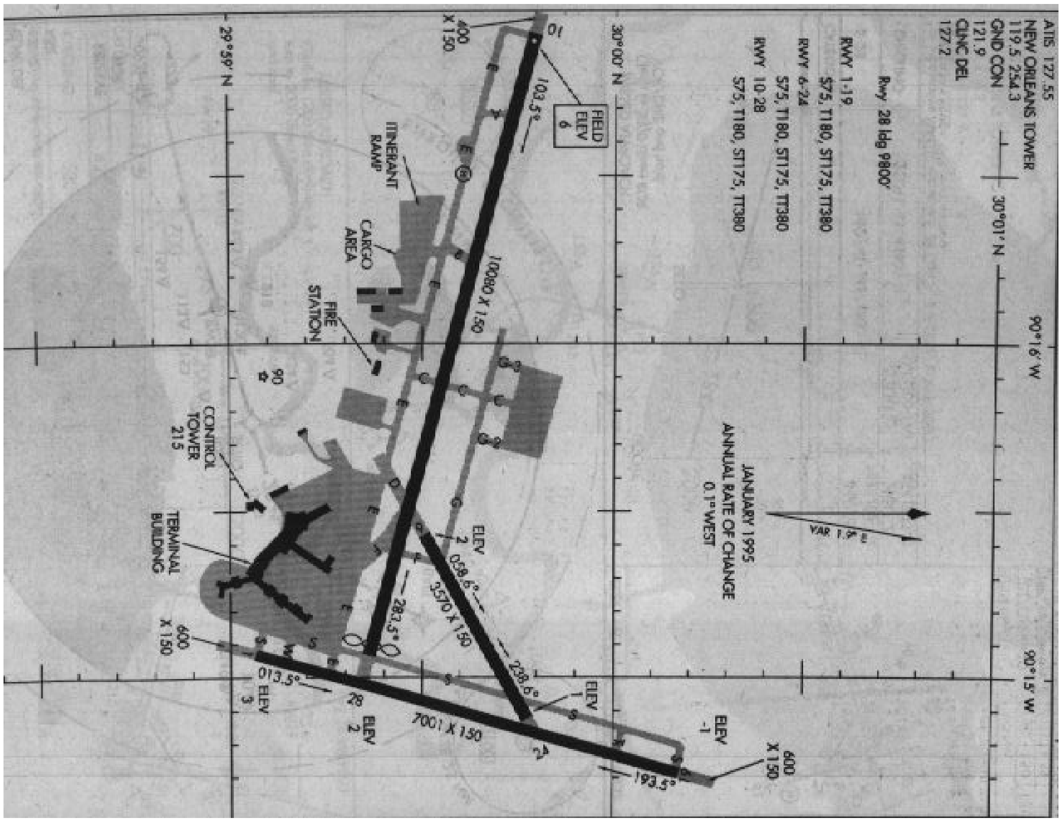
MINNEAPOLIS - SAINT PAUL





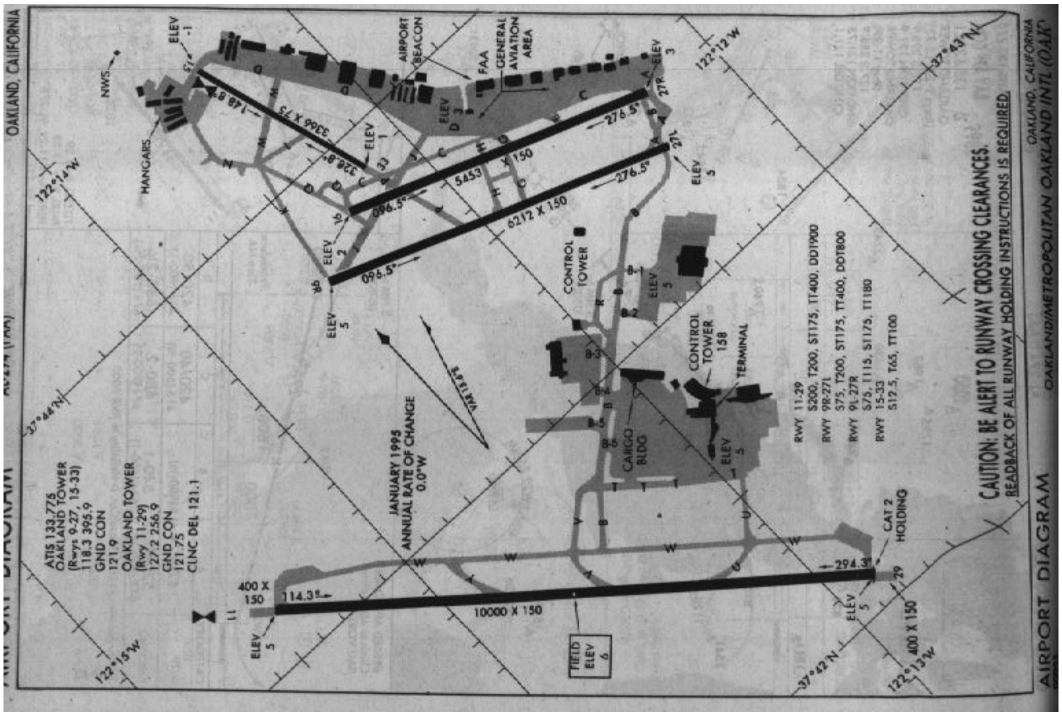
MINNEAPOLIS - SAINT PAUL

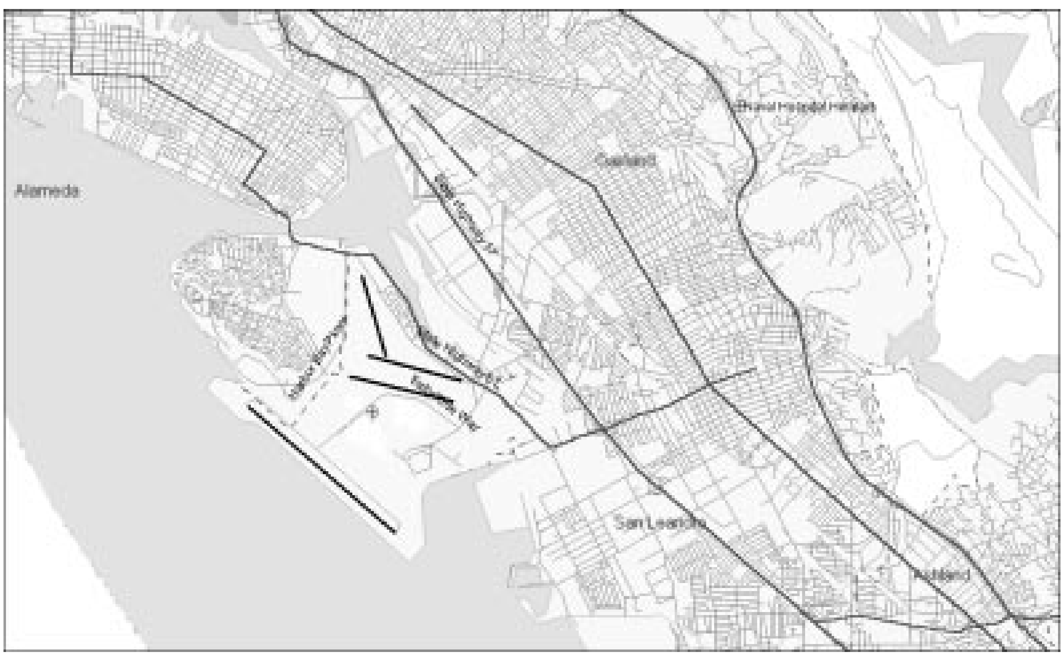
NEW ORLEANS - MOISANT FIELD



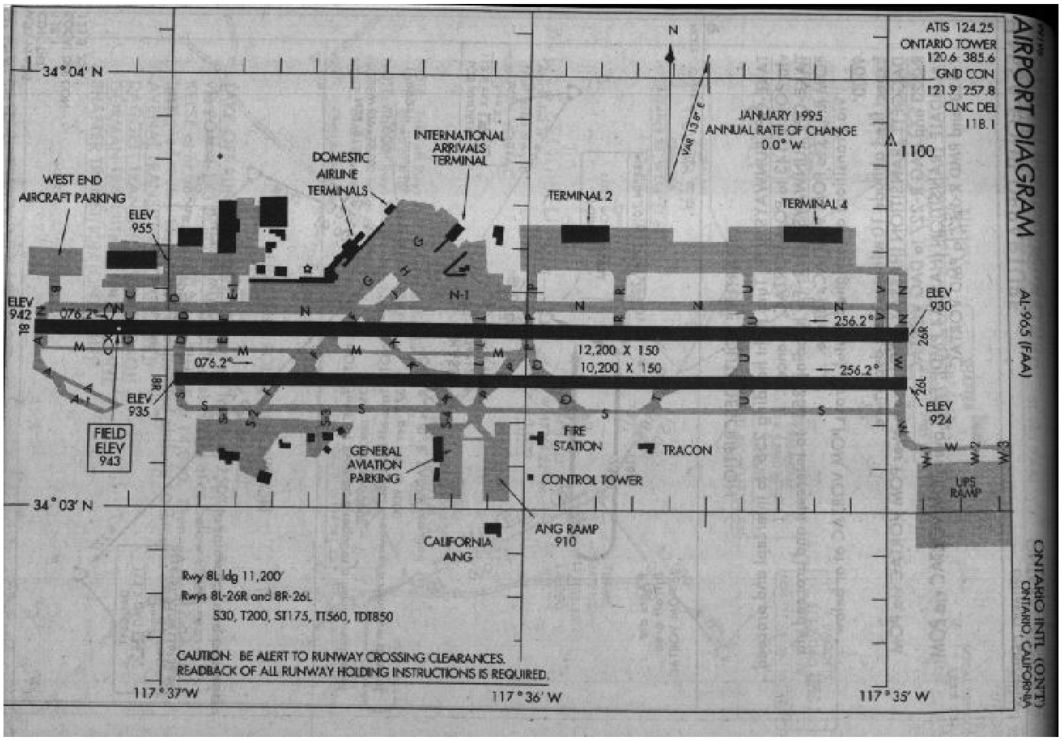
NEW ORLEANS - MOISANT FIELD - AERIAL PHOTO

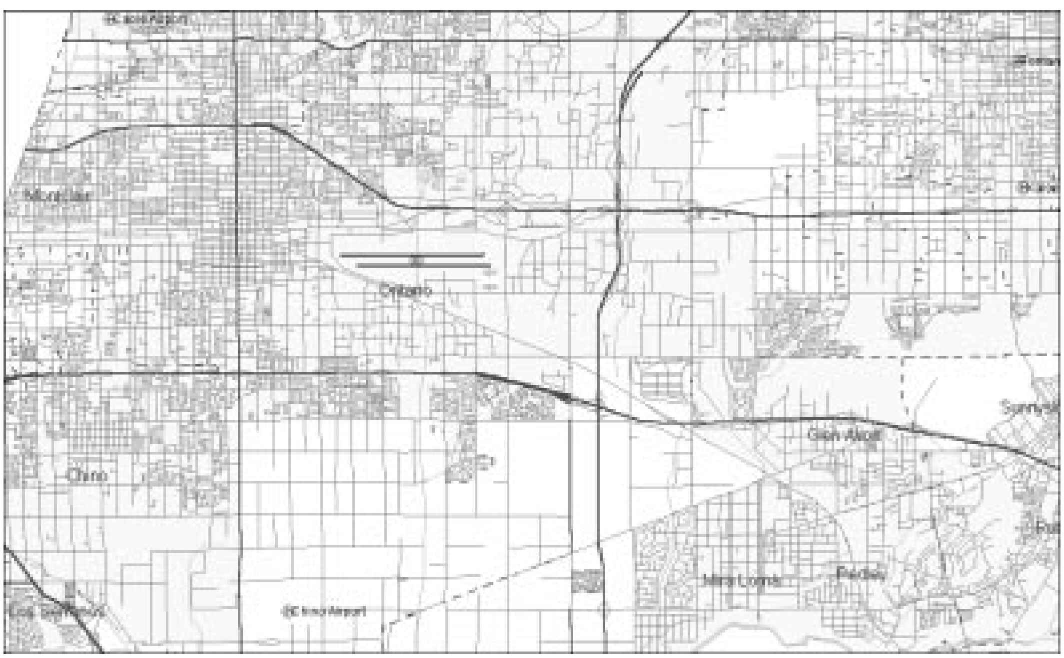
OAKLAND



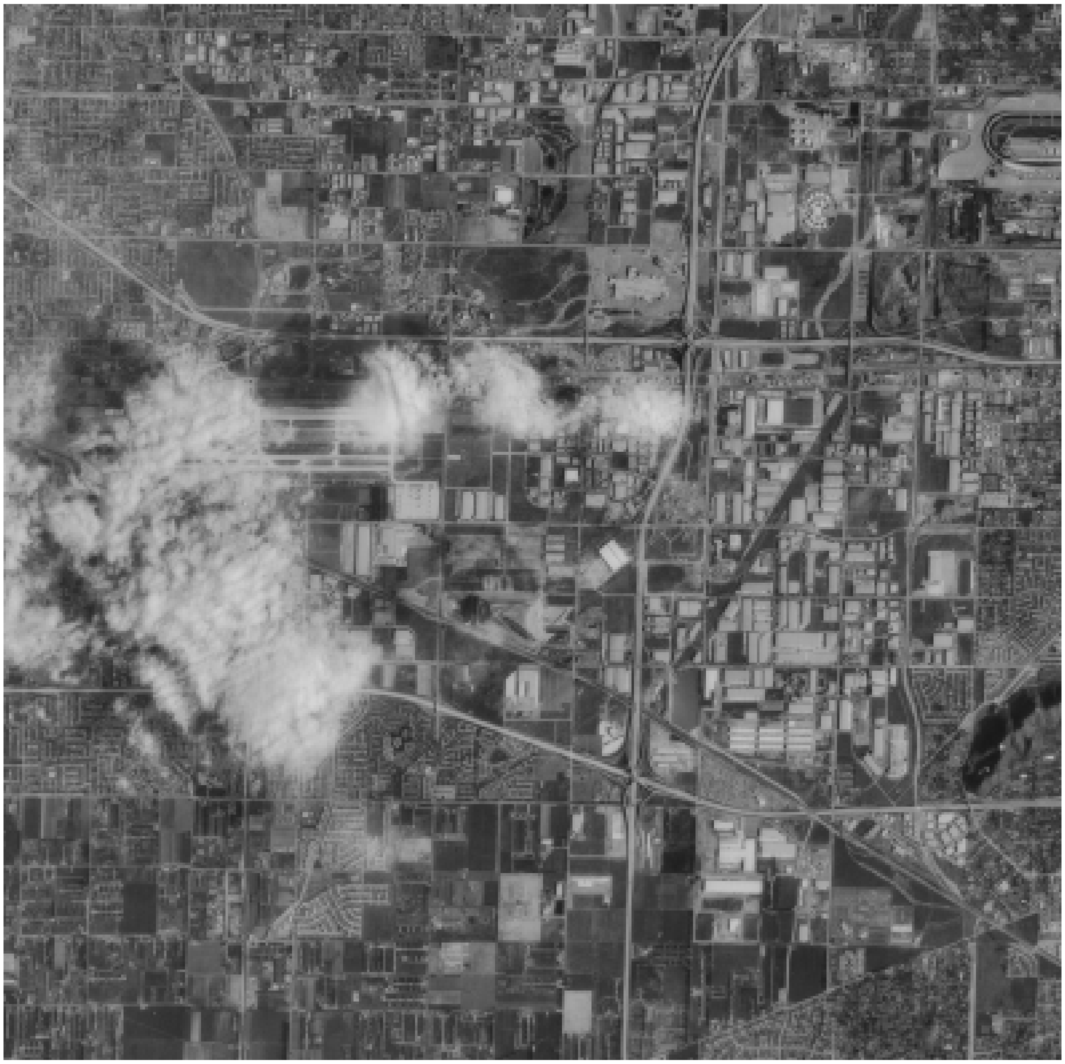


ONTARIO

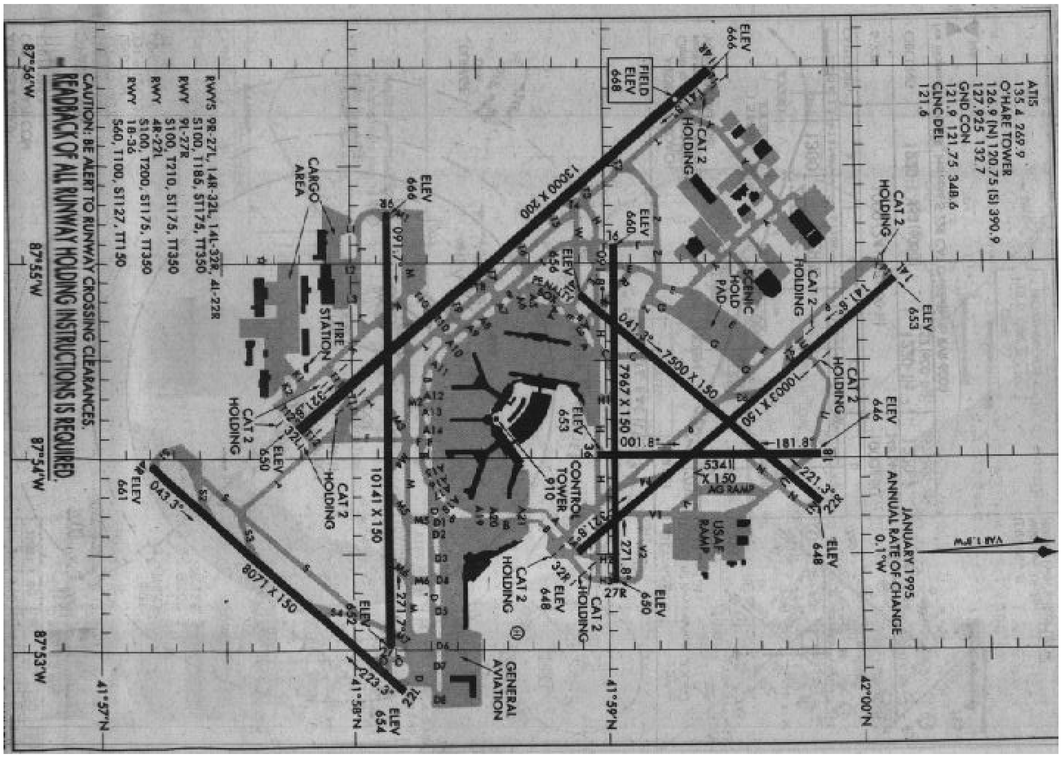

ATIS 124.25
ONTARIO TOWER
120.6 385.6
GND CON
121.9 257.8
CLNC DEL
118.1
AIRPORT DIAGRAM
AL-965 (FAA)
JANUARY 1995
ANNUAL RATE OF CHANGE
0.0° W
INTERNATIONAL
ARRIVALS
TERMINAL
DOMESTIC
AIRLINE
TERMINALS
WEST END
AIRCRAFT PARKING
TERMINAL 2
TERMINAL 4
ELEV
955
ELEV
942
ELEV
930
ELEV
935
ELEV
924
FIELD
ELEV
943
12,200 X 150
10,200 X 150
076.2°
256.2°
GENERAL
AVIATION
PARKING
FIRE
STATION
TRACON
CONTROL TOWER
UPS
RAMP
CALIFORNIA
ANG
ANG RAMP
910
34° 04' N
34° 03' N
117° 37' W
117° 36' W
117° 35' W
Rwy 8L ldg 11,200'
Rwys 8L-26R and 8R-26L
S30, T200, ST175, TT560, TDT850
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES.
READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
ONTARIO INTL (ONT)
ONTARIO, CALIFORNIA

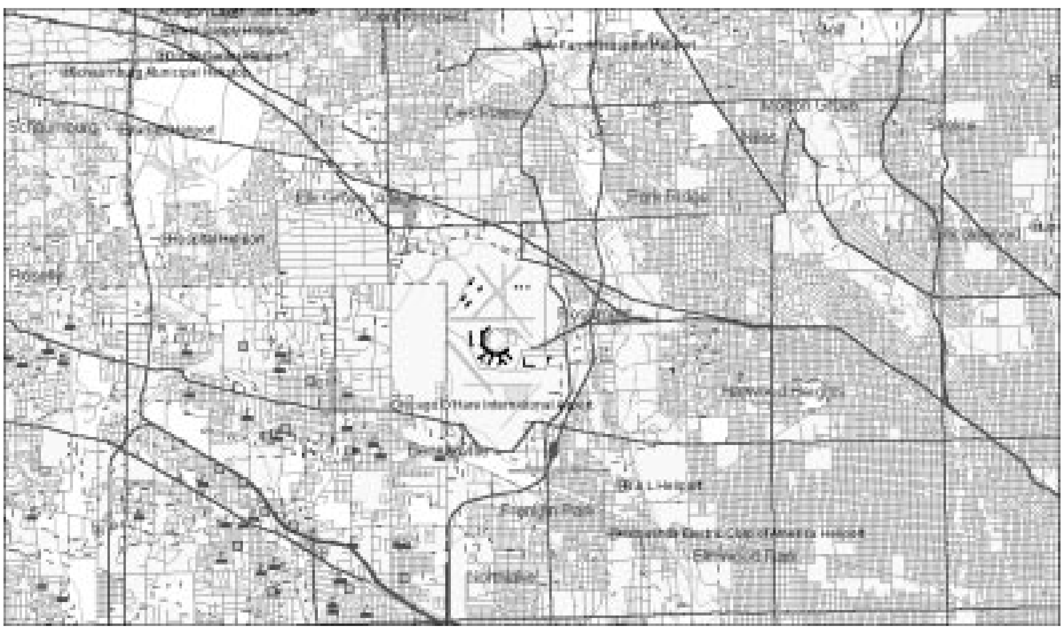

Montclair
Ontario
Chino
Glen Avon
Mira Loma
Pedley

ONTARIO SATELLITE PHOTO



CHICAGO O'HARE



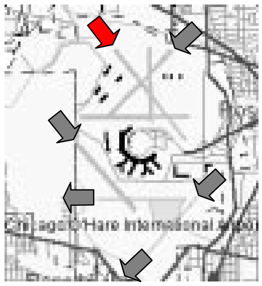


CHICAGO O'HARE SATELLITE PHOTO

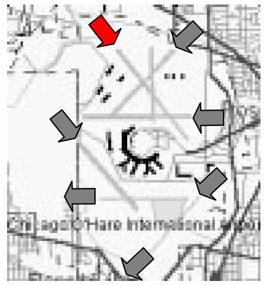
CHICAGO O'HARE CONFIGURATIONS

O’Hare configurations:

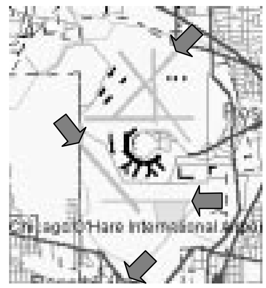
Groups1&2 (Plan B, Plan X)



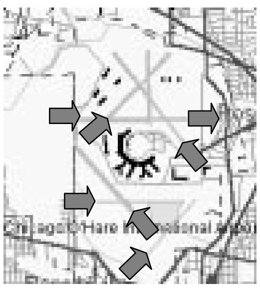
Plan B Trip 22



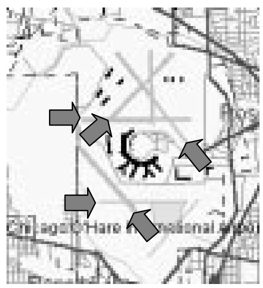
Plan B Trip 27



Plan B



Plan X



Mod Plan X

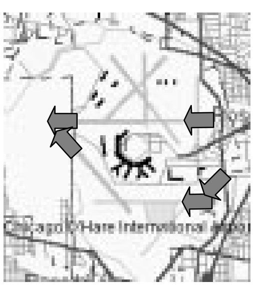
Key:

Arrow in front of runway: arrivals
Arrow at end of runway: departures

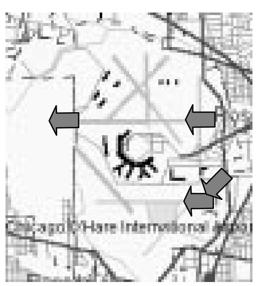
- Props only
- Props and Jets
- Props and Jets, no heavies

O’Hare Configurations 3:

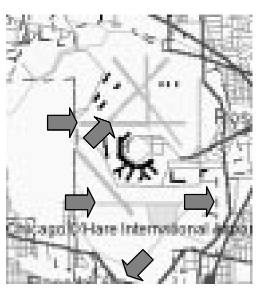
parallel 9s



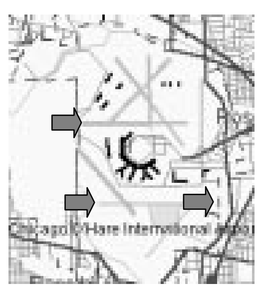
P9s depart 32R 22L



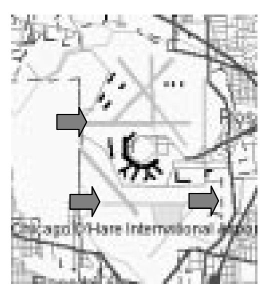
P9s depart 22L



P9s depart 4L 22L

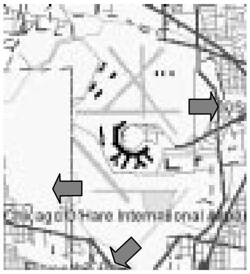


P9s depart 4L

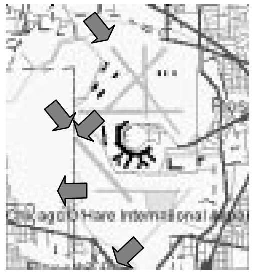


P9s depart 32R

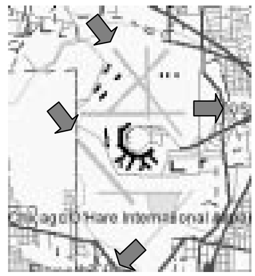
O’Hare Configurations 4:
Parallel 14s



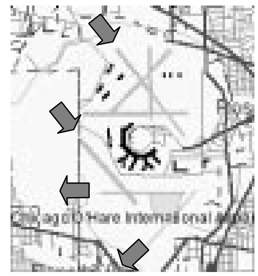
P14s



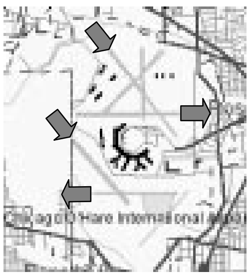
P14s no depart 9



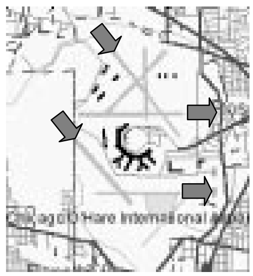
P14s no depart 27



P14s no depart 9 or 4

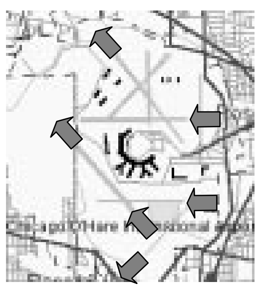


P14s no depart 22

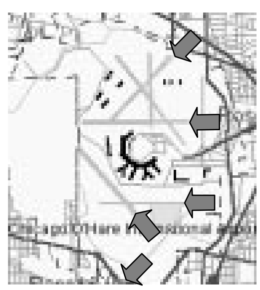


P14s depart 9s

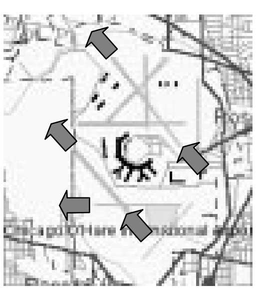
O’Hare Configurations 5:
P27s, P32s, P22s



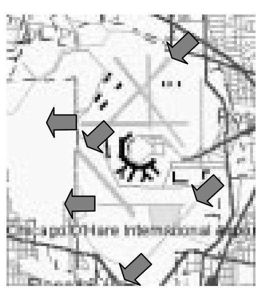
Parallel 27 Trip 32L



Plan Weird Trip 27

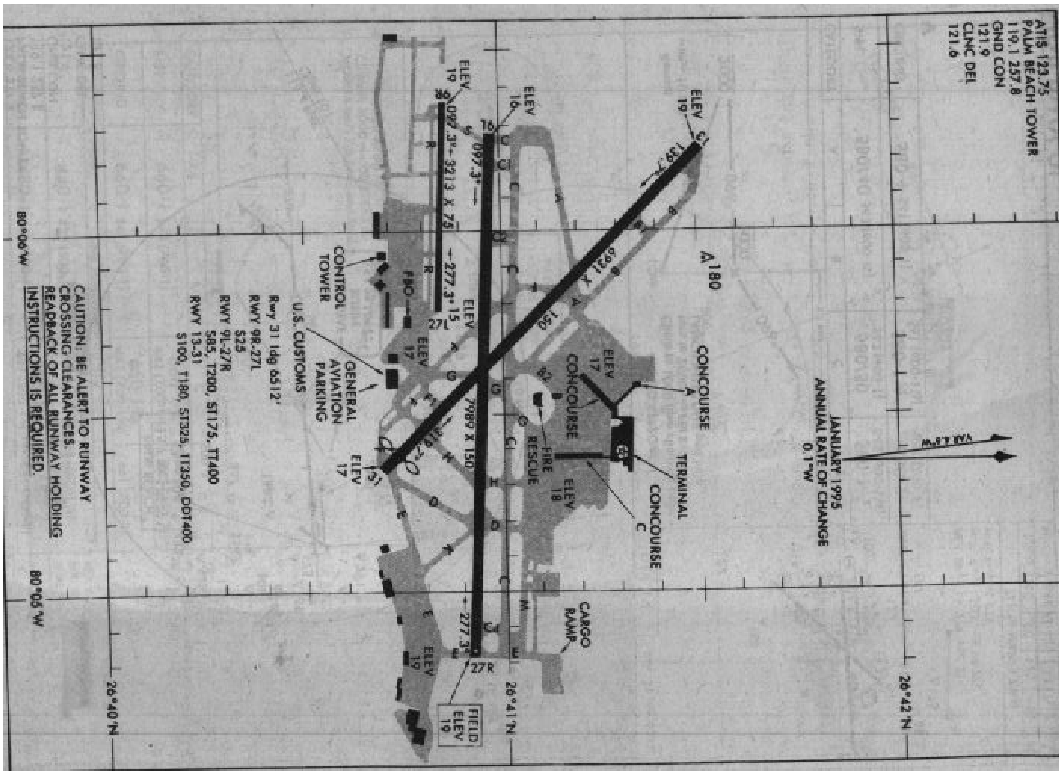


P32s

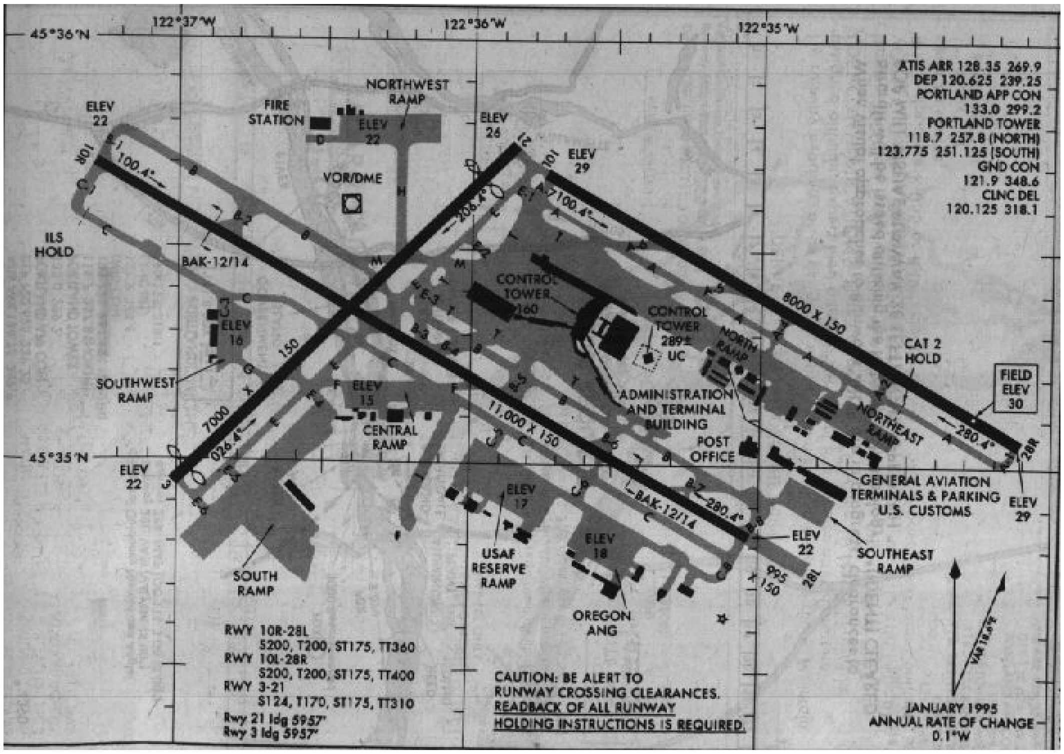


P22s

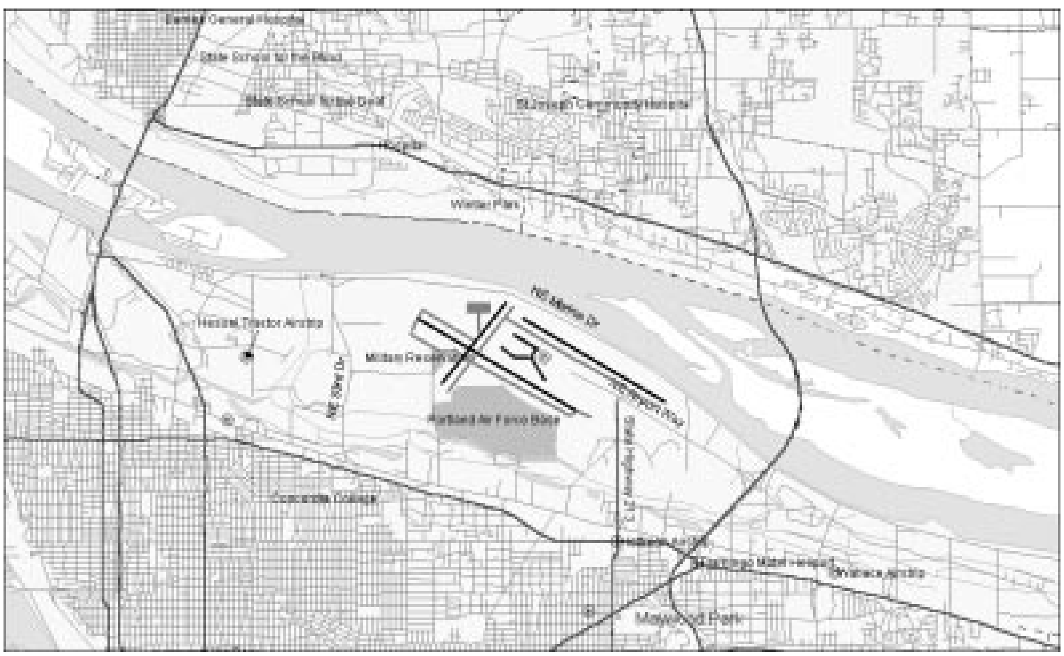
PALM BEACH INTERNATIONAL



PORTLAND

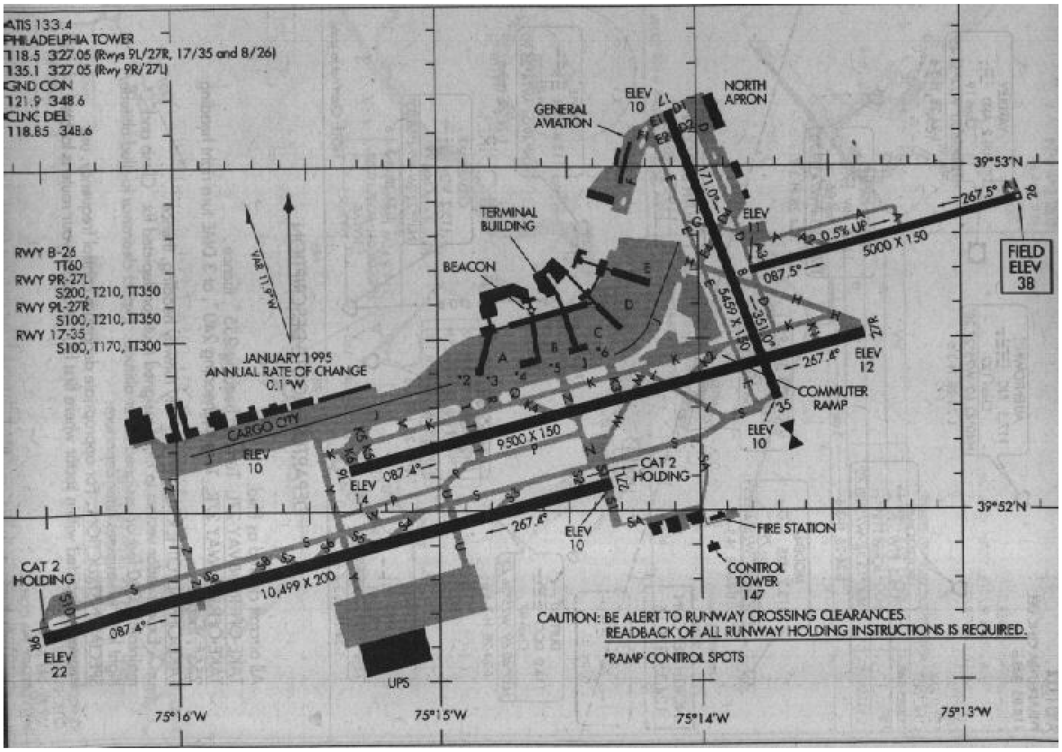


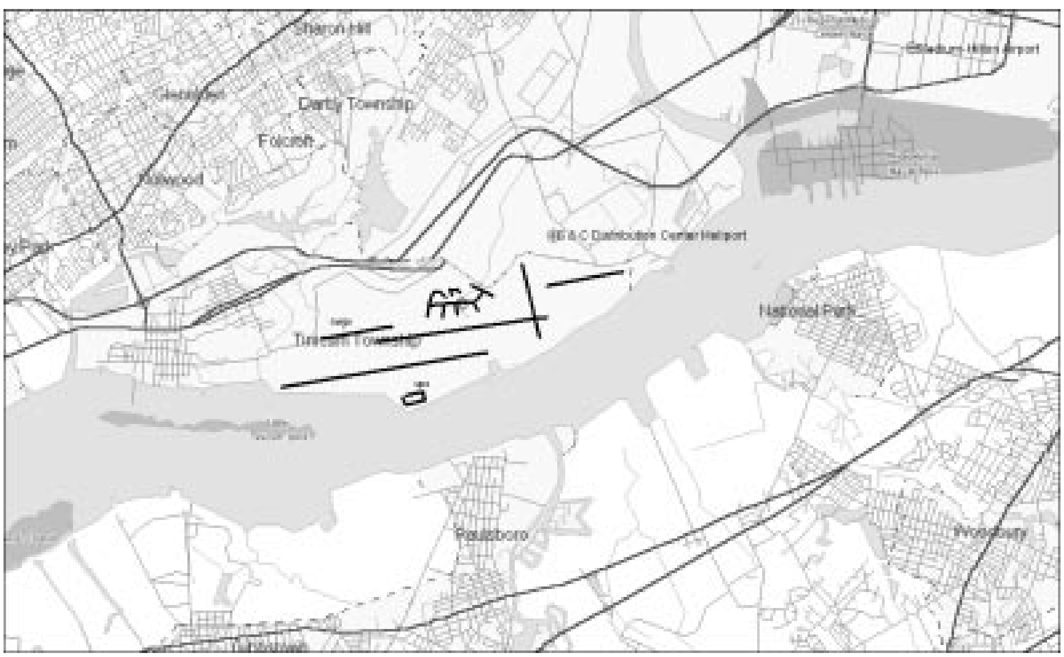
ATIS ARR 128.35 269.9
DEP 120.625 239.25
PORTLAND APP CON
133.0 299.2
PORTLAND TOWER
118.7 257.8 (NORTH)
123.775 251.125 (SOUTH)
GND CON
121.9 348.6
CLNC DEL
120.125 318.1
NORTHWEST RAMP
FIRE STATION
VOR/DME
ILS HOLD
BAK-12/14
CONTROL TOWER 160
CONTROL TOWER 289± UC
NORTH RAMP
8000 X 150
CAT 2 HOLD
FIELD ELEV 30
SOUTHWEST RAMP
CENTRAL RAMP
ADMINISTRATION AND TERMINAL BUILDING
NORTHEAST RAMP
11,000 X 150
POST OFFICE
GENERAL AVIATION TERMINALS & PARKING U.S. CUSTOMS
SOUTH RAMP
USAF RESERVE RAMP
OREGON ANG
SOUTHEAST RAMP
RWY 10R-28L
S200, T200, ST175, TT360
RWY 10L-28R
S200, T200, ST175, TT400
RWY 3-21
S124, T170, ST175, TT310
Rwy 21 ldg 5957'
Rwy 3 ldg 5957'
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES.
READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
JANUARY 1995
ANNUAL RATE OF CHANGE 0.1°W



Portland Air Force Base
Concordia College
Maywood Park

PHILADELPHIA





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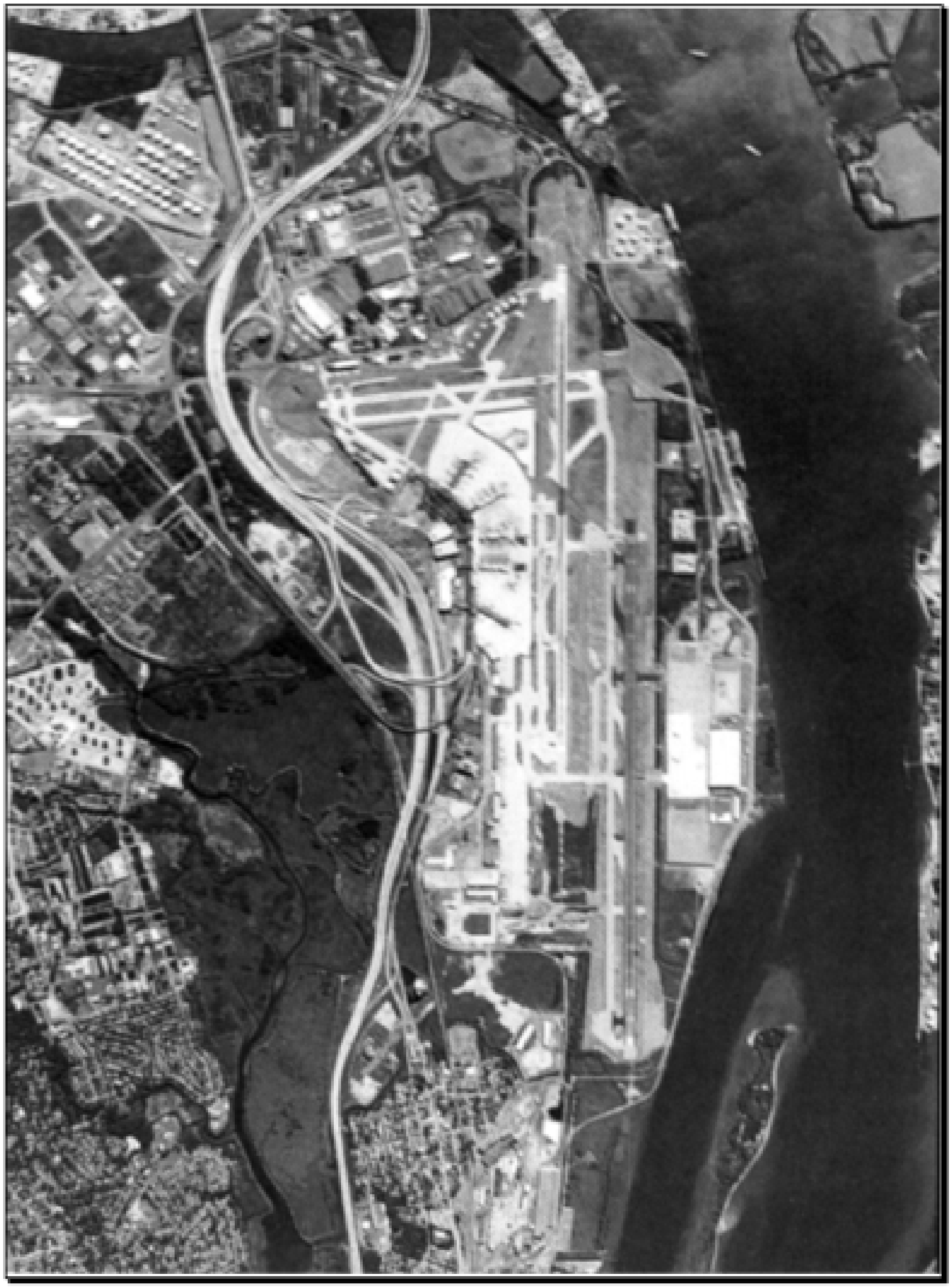
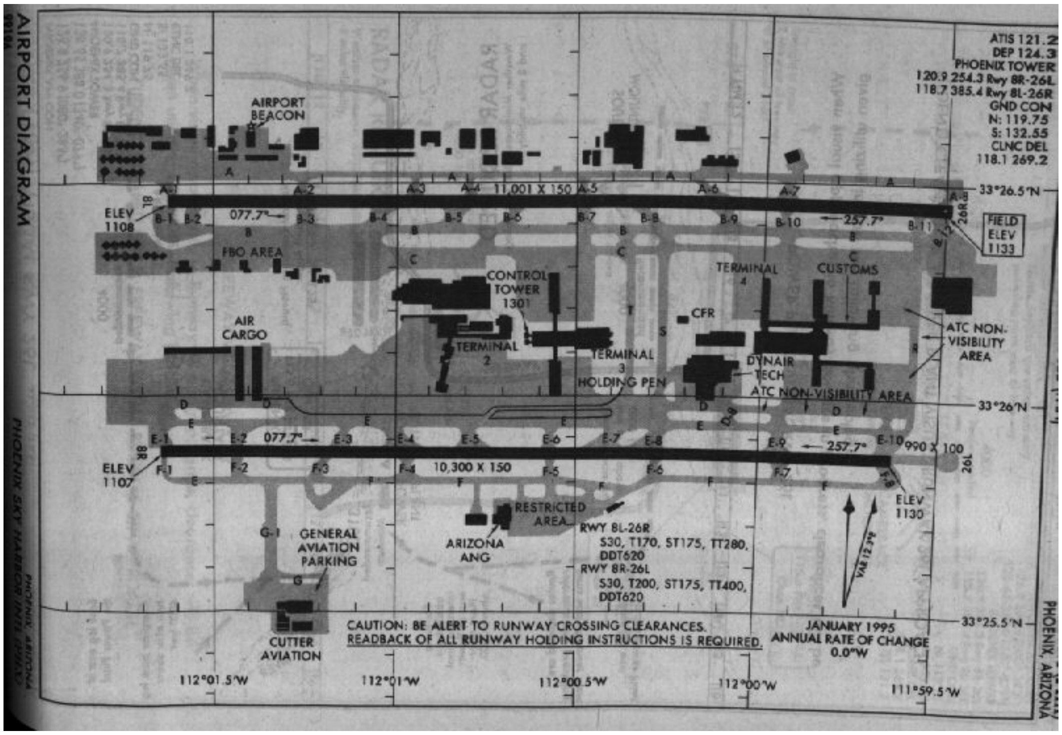
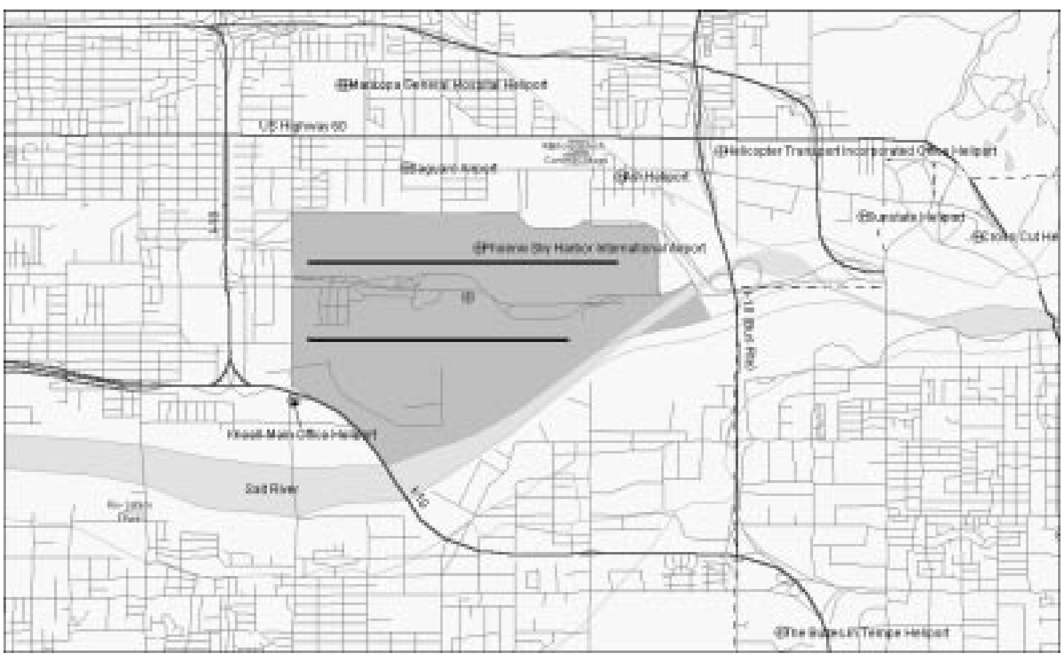
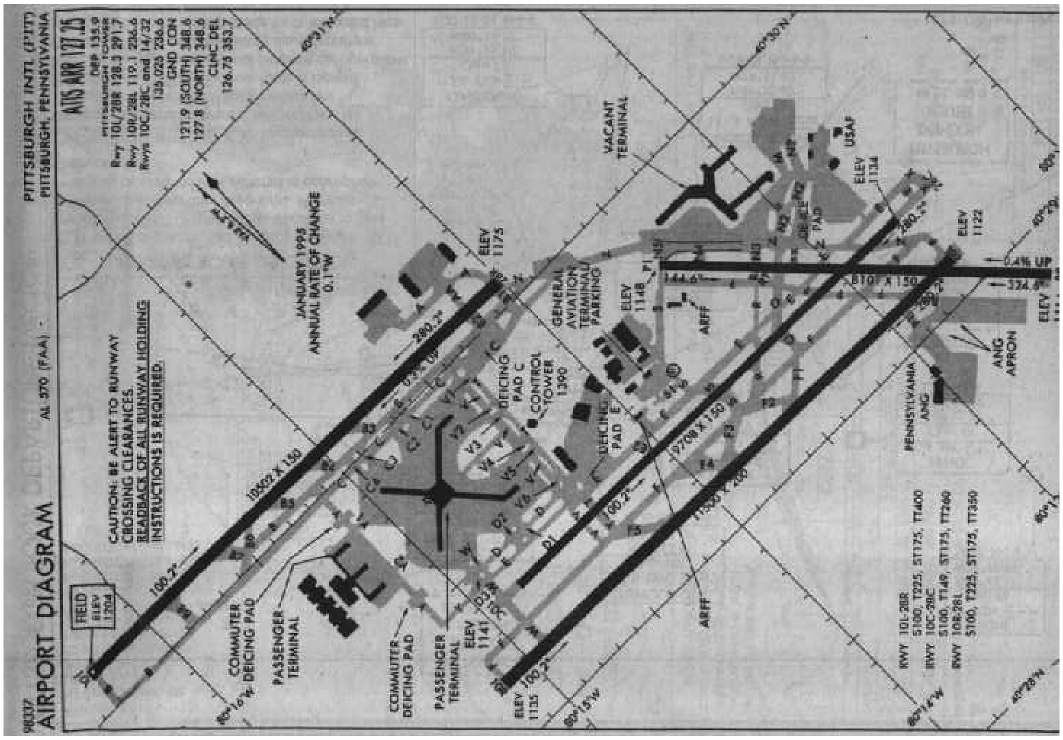


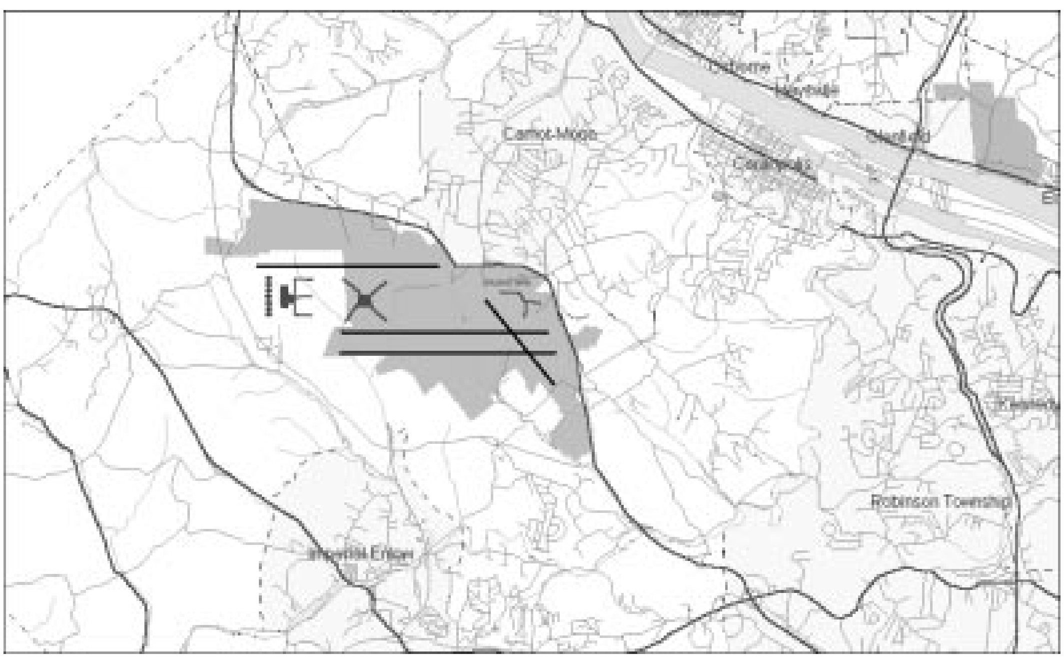
PHOENIX


AIRPORT DIAGRAM
ATIS 121.2
DEP 124.3
PHOENIX TOWER
120.9 254.3 Rwy 8R-26L
118.7 385.4 Rwy 8L-26R
GND CON
N: 119.75
S: 132.55
CLNC DEL
118.1 269.2
AIRPORT BEACON
11,001 X 150
33°26.5'N
ELEV 1108
077.7°
257.7°
FIELD ELEV 1133
FBO AREA
CONTROL TOWER 1301
TERMINAL 4
CUSTOMS
AIR CARGO
CFR
TERMINAL 2
TERMINAL 3
HOLDING PEN
DYNAIR TECH
ATC NON-VISIBILITY AREA
33°26'N
10,300 X 150
990 X 100
ELEV 1107
ELEV 1130
RESTRICTED AREA
GENERAL AVIATION PARKING
ARIZONA ANG
RWY 8L-26R
S30, T170, ST175, TT280, DDT620
RWY 8R-26L
S30, T200, ST175, TT400, DDT620
33°25.5'N
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES.
READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
JANUARY 1995
ANNUAL RATE OF CHANGE
0.0°W
CUTTER AVIATION
112°01.5'W
112°01'W
112°00.5'W
112°00'W
111°59.5'W
PHOENIX, ARIZONA
PHOENIX SKY HARBOR INTL (PHX)


US Highway 60
Salt River

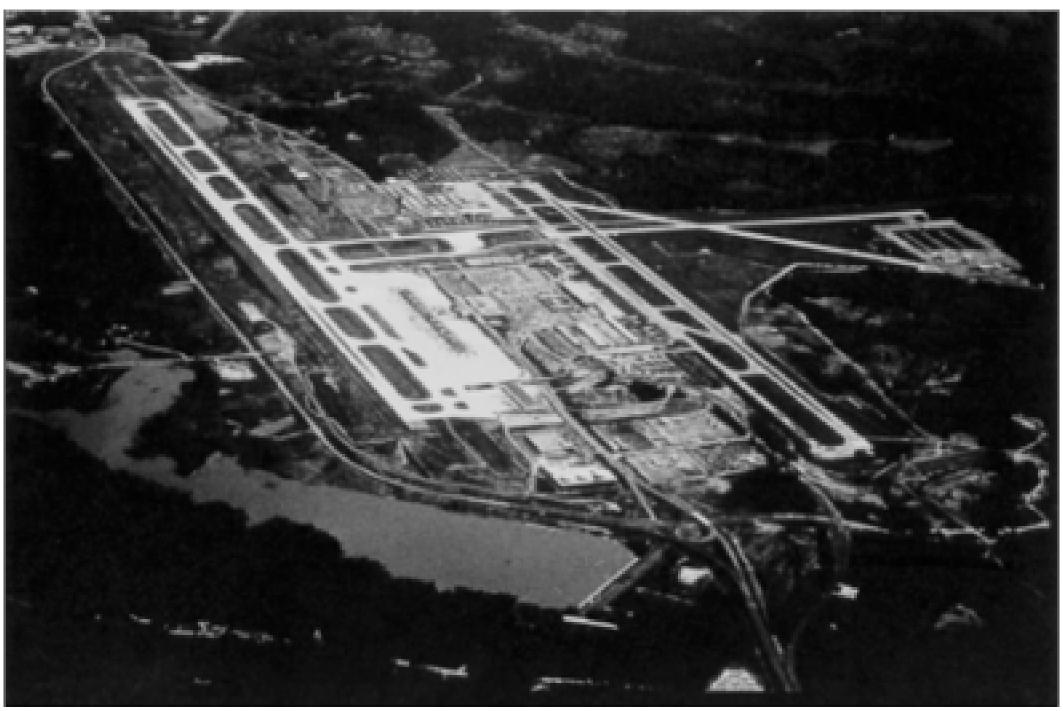
PITTSBURGH


AIRPORT DIAGRAM
PITTSBURGH INTL (PIT)
PITTSBURGH, PENNSYLVANIA
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES. READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
JANUARY 1995 ANNUAL RATE OF CHANGE 0.1°W
VACANT TERMINAL
GENERAL AVIATION TERMINAL/ PARKING
CONTROL TOWER
PASSENGER TERMINAL
COMMUTER DEICING PAD
PENNSYLVANIA ANG
ANG APRON
USAF
ARFF

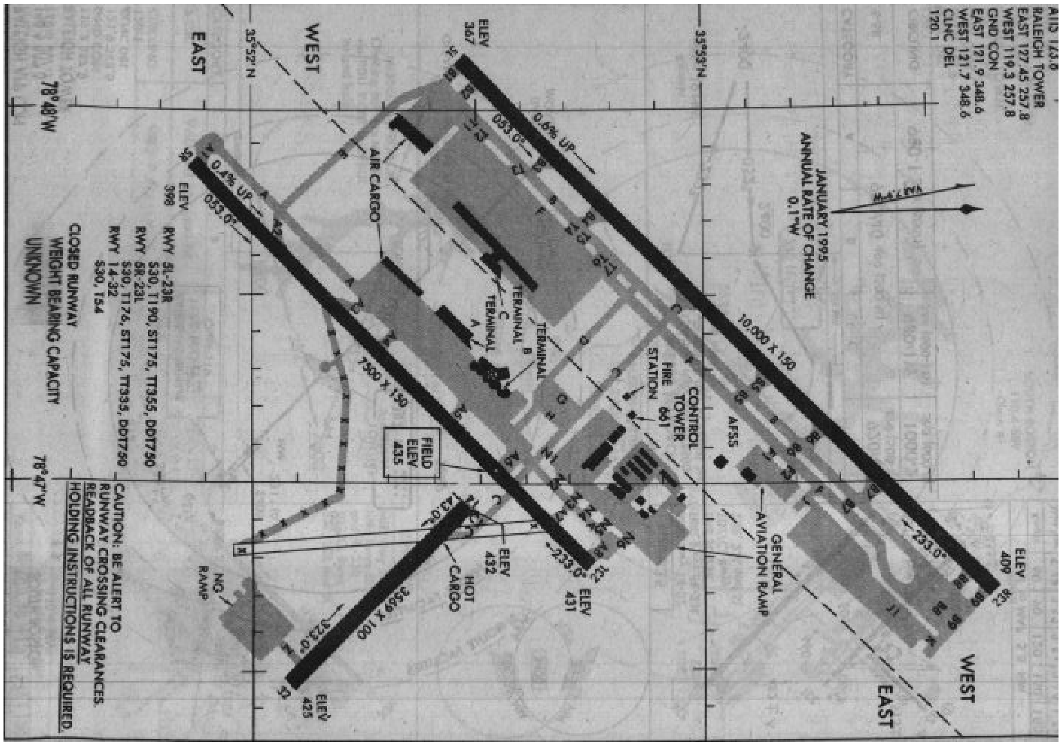

Carnot-Moon
Coraopolis
Robinson Township

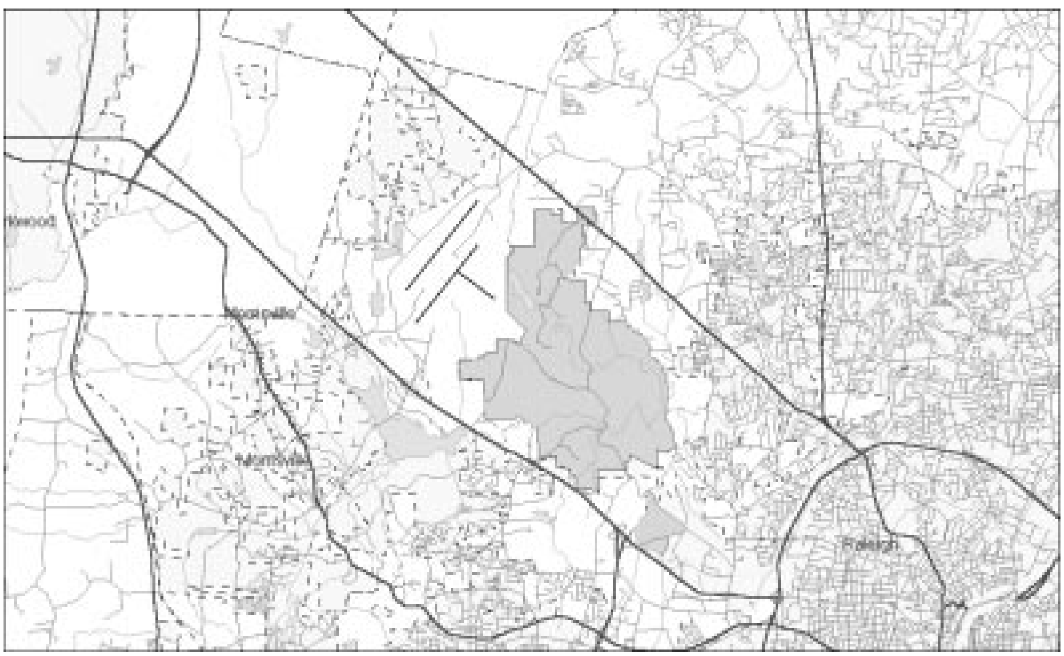
PITTSBURGH

RALEIGH DURHAM

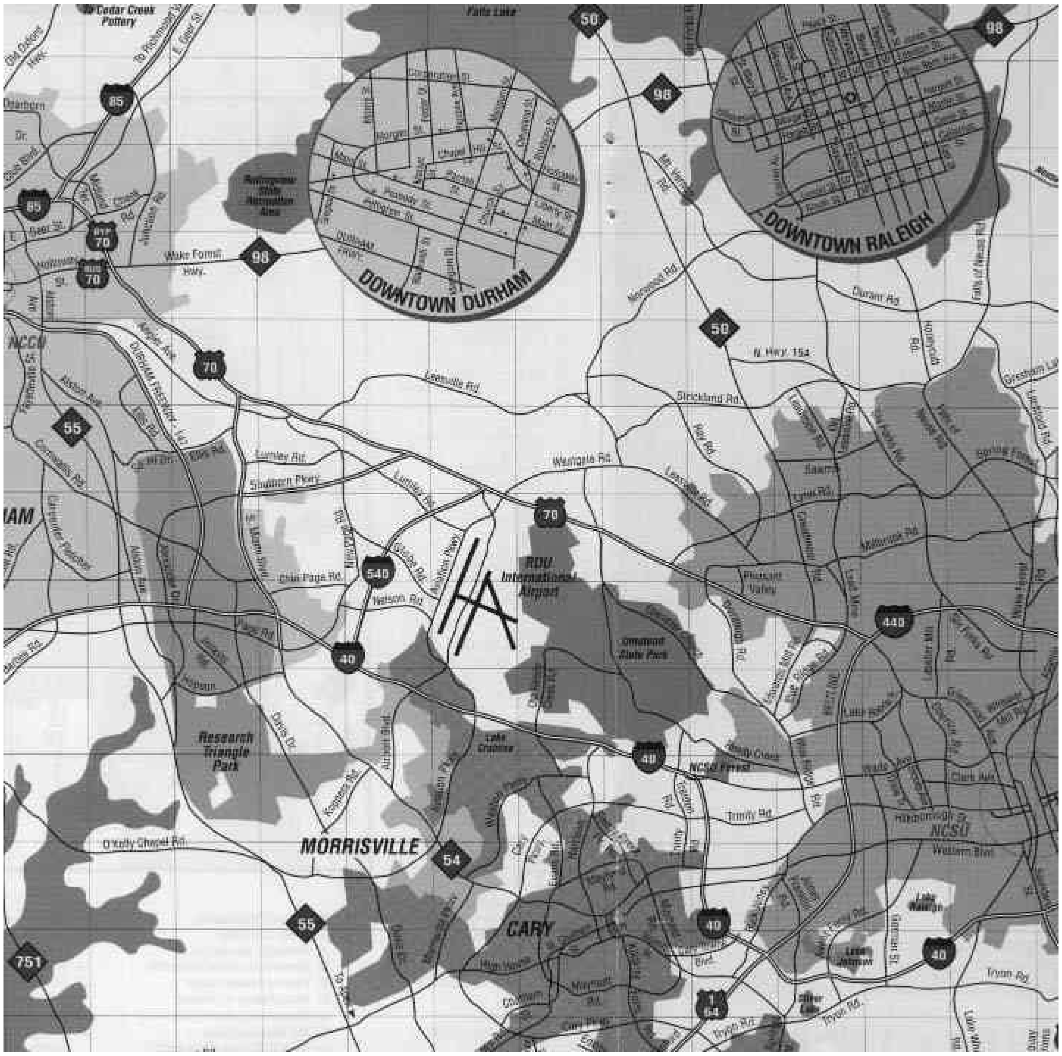


RALEIGH-DURHAM



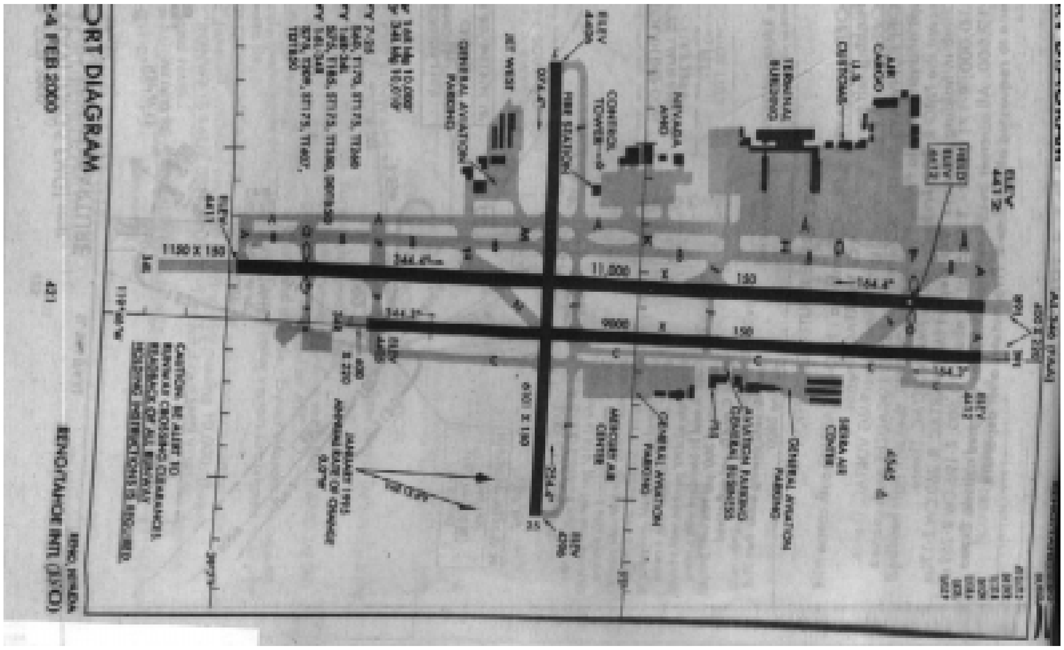


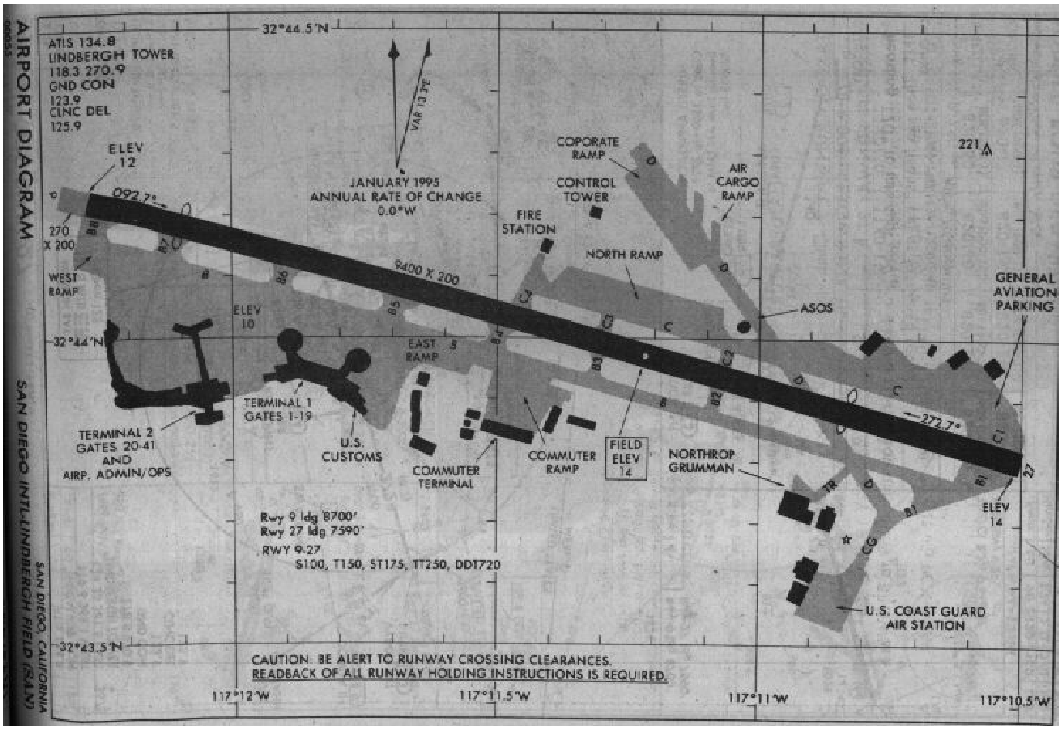
RALEIGH-DURHAM

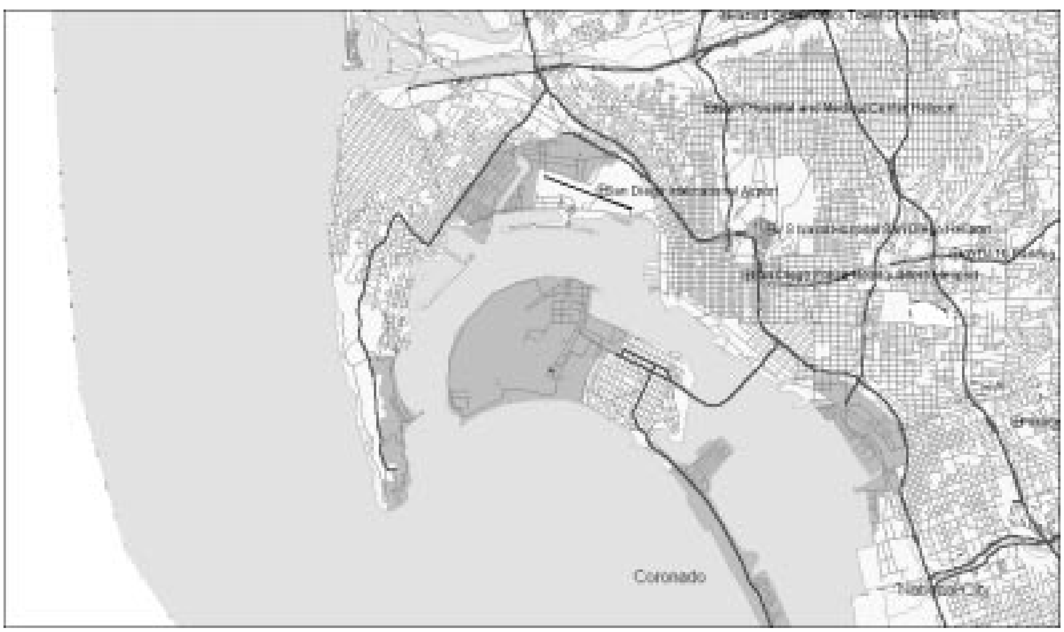


RALEIGH-DURHAM: AIRFIELD VIEWS

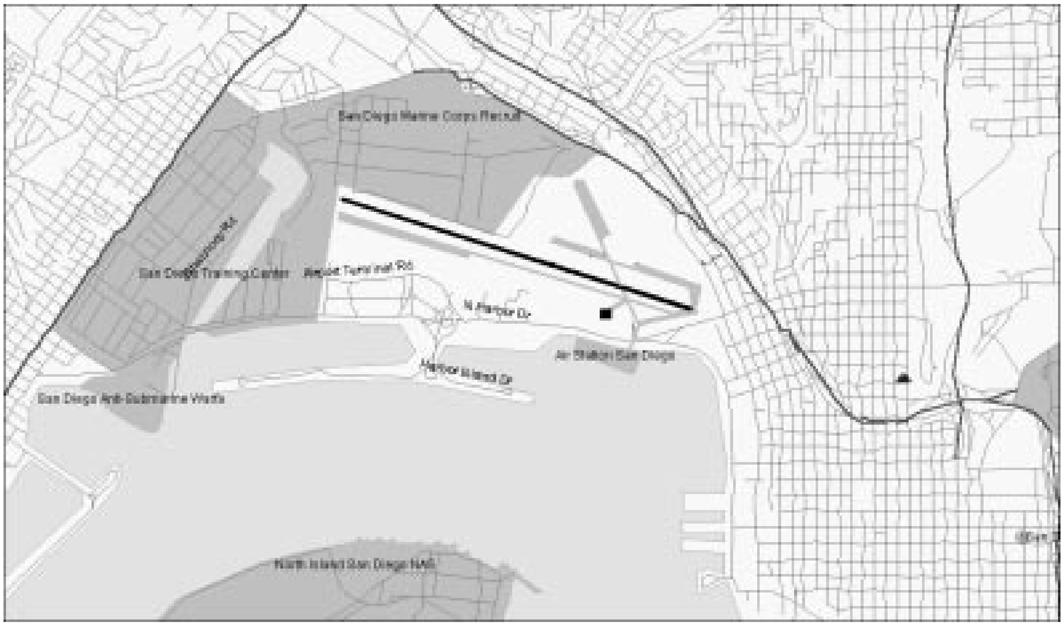
RENO



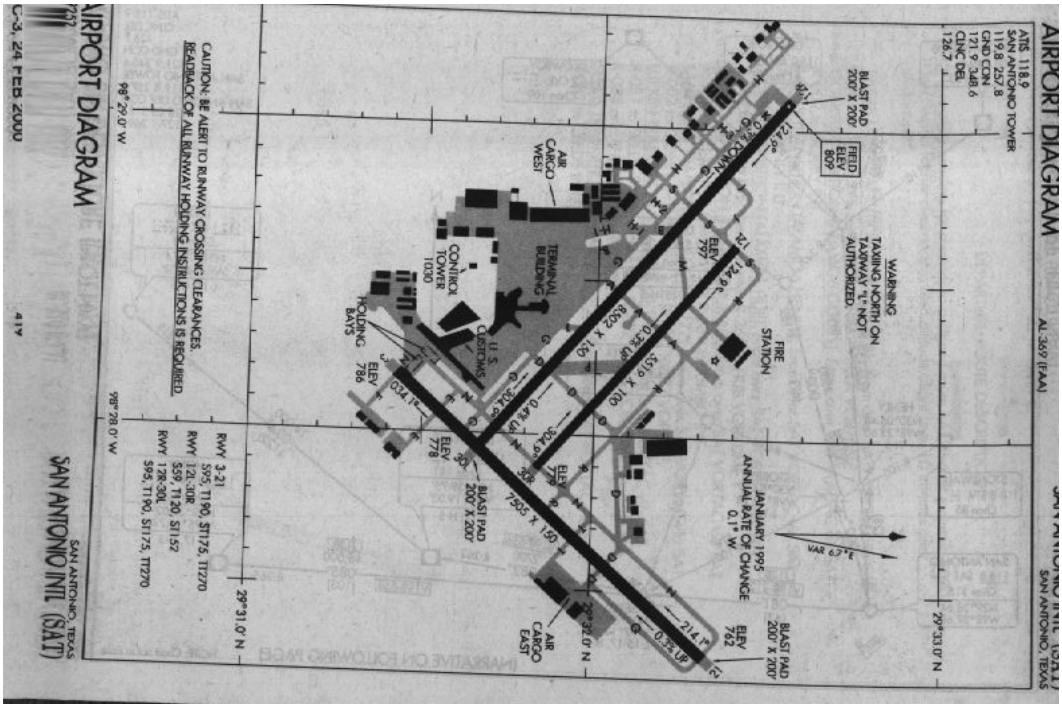

AIRPORT DIAGRAM
ATIS 134.8
LINDBERGH TOWER
118.3 270.9
GND CON
123.9
CLNC DEL
125.9
32°44.5'N
JANUARY 1995
ANNUAL RATE OF CHANGE
0.0°W
COPORATE RAMP
CONTROL TOWER
AIR CARGO RAMP
FIRE STATION
NORTH RAMP
221
ELEV 12
092.7°
270 X 200
WEST RAMP
9400 X 200
ELEV 10
32°44'N
EAST RAMP
ASOS
GENERAL AVIATION PARKING
TERMINAL 2
GATES 20-41
AND
AIRP. ADMIN/OPS
TERMINAL 1
GATES 1-19
U.S. CUSTOMS
COMMUTER TERMINAL
COMMUTER RAMP
FIELD ELEV 14
NORTHROP GRUMMAN
272.7°
ELEV 14
Rwy 9 ldg 8700'
Rwy 27 ldg 7590'
RWY 9-27
S100, T150, ST175, TT250, DDT720
U.S. COAST GUARD AIR STATION
32°43.5'N
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES.
READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
117°12'W
117°11.5'W
117°11'W
117°10.5'W
SAN DIEGO, CALIFORNIA
SAN DIEGO INTL-LINDBERGH FIELD (SAN)

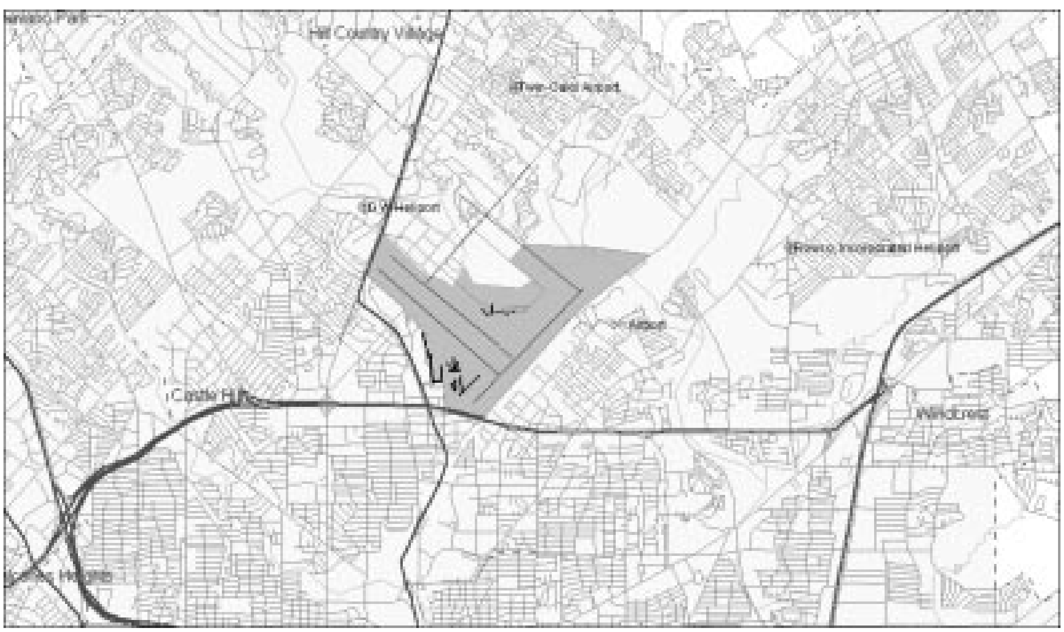

Coronado

SAN DIEGO

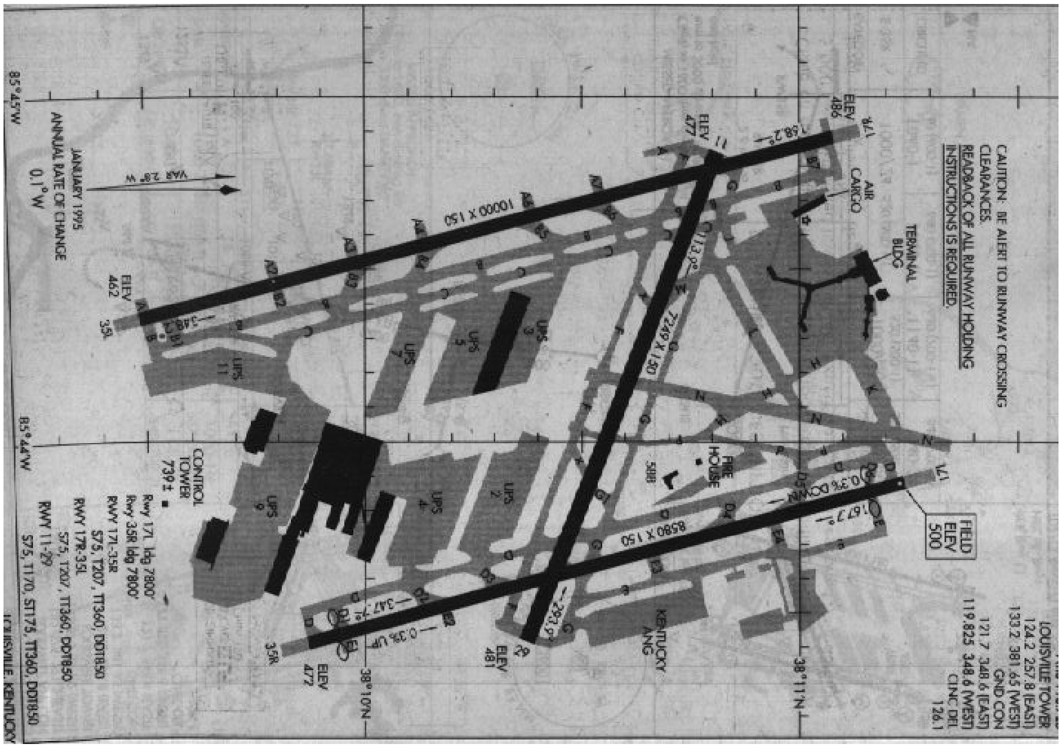

San Diego Marine Corps Recruit
San Diego Training Center
Airport Terminal Rd
N Harbor Dr
Air Station San Diego
Harbor Island Dr
North Island San Diego NAS

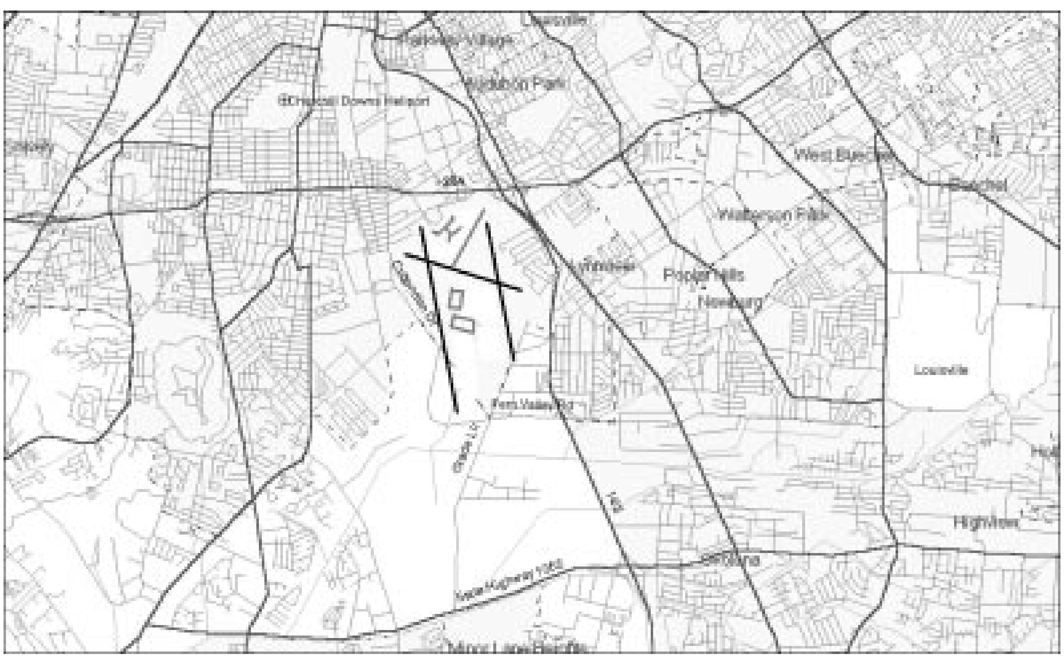
SAN ANTONIO





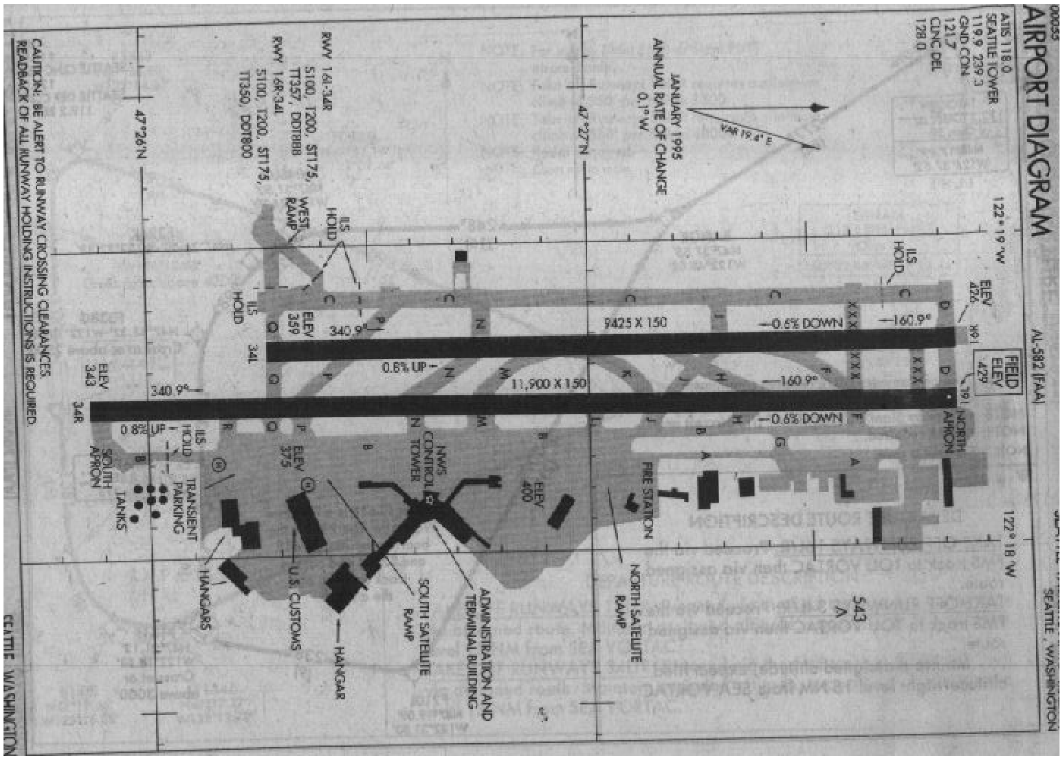
LOUISVILLE - STANDIFORD

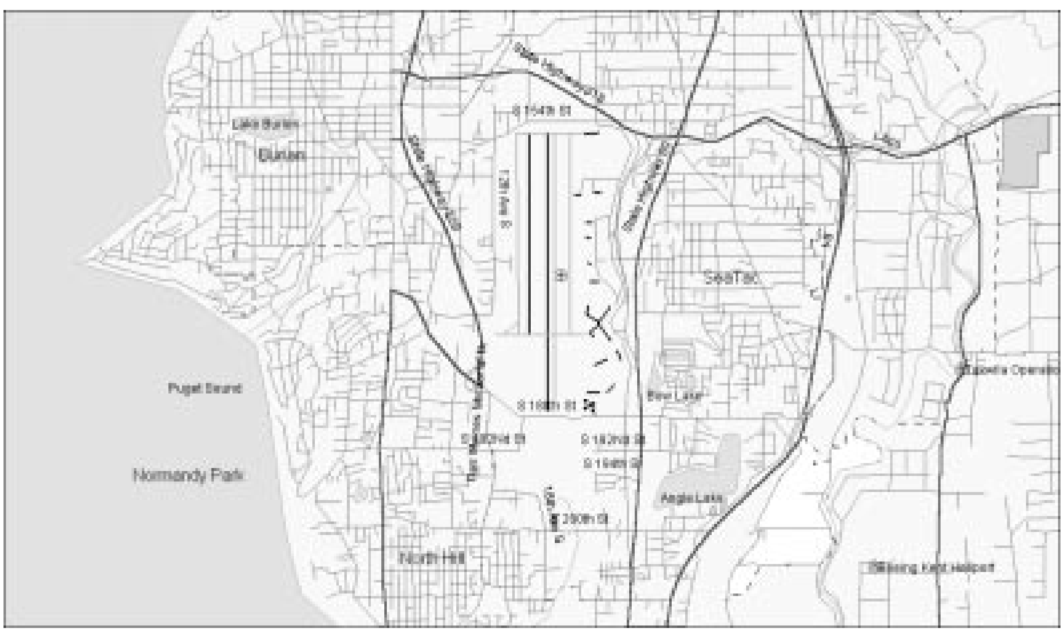




LOUISVILLE - STANDIFORD

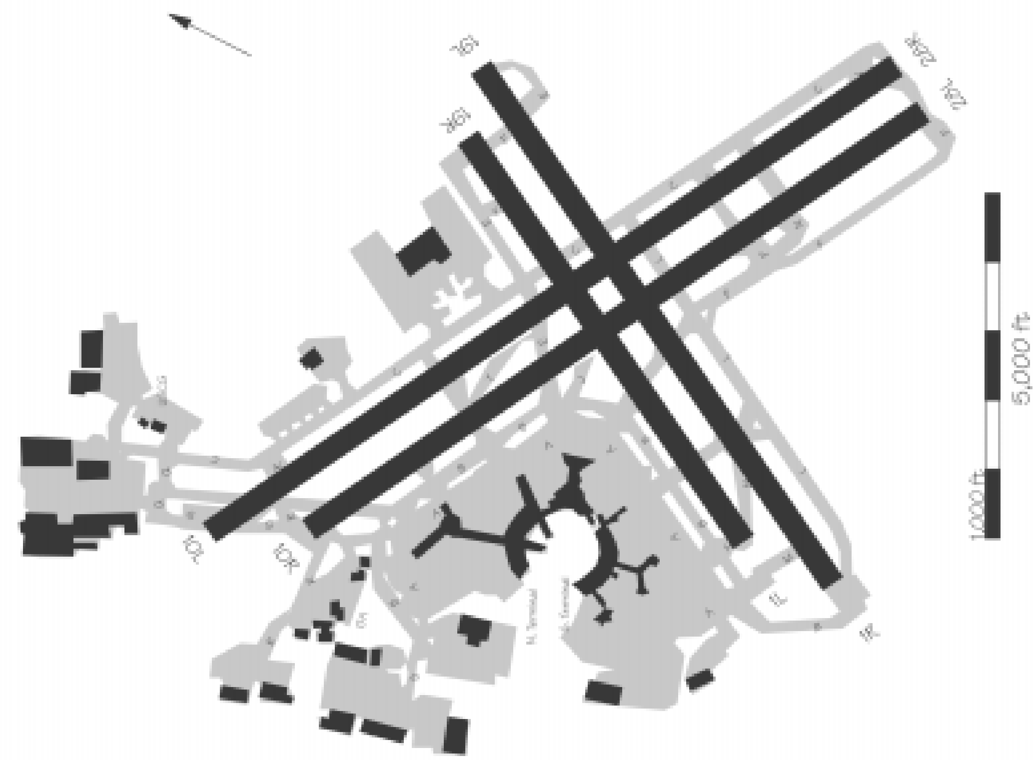
SEATTLE

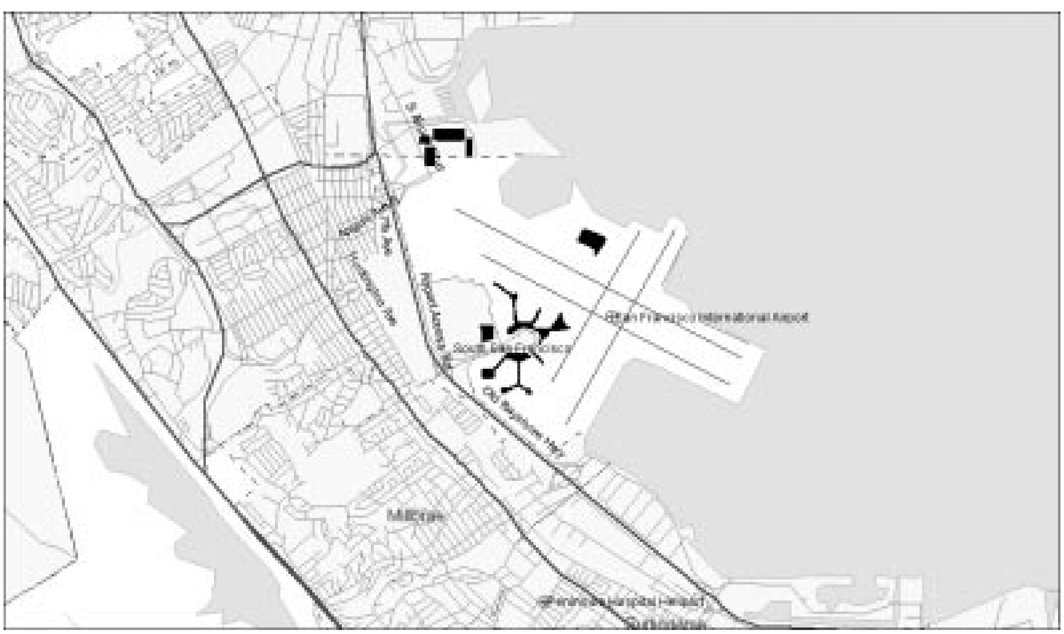




SEATTLE

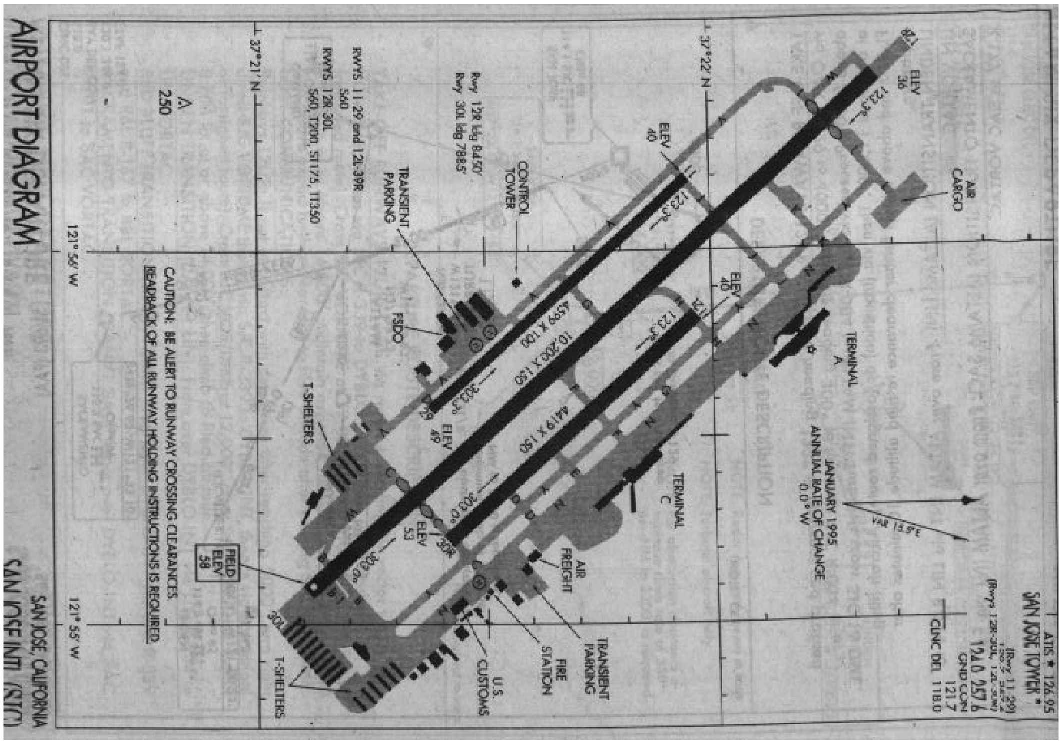
SAN FRANCISCO

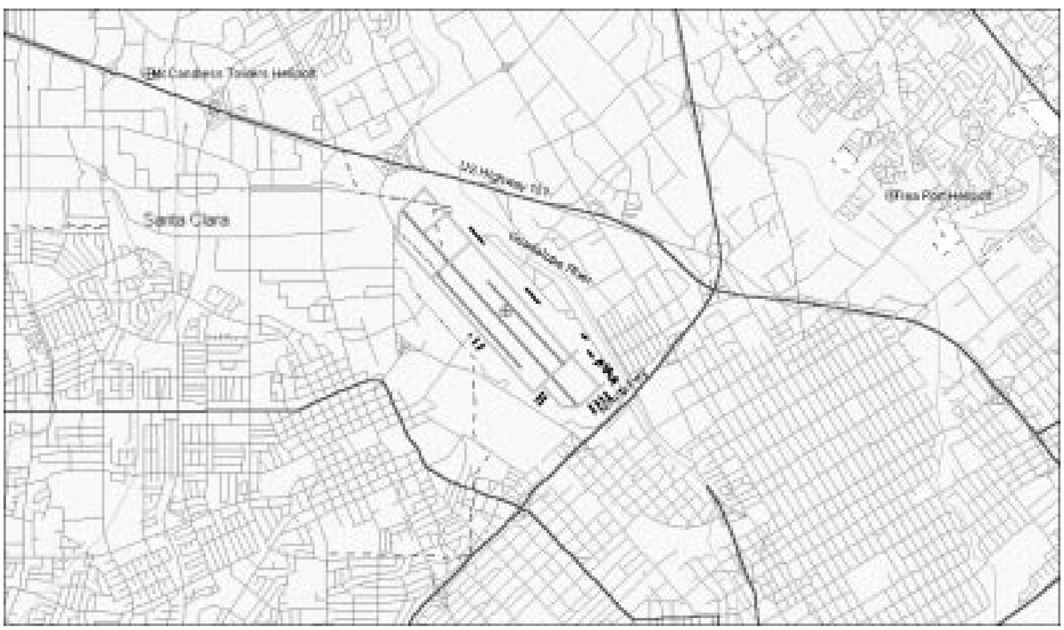




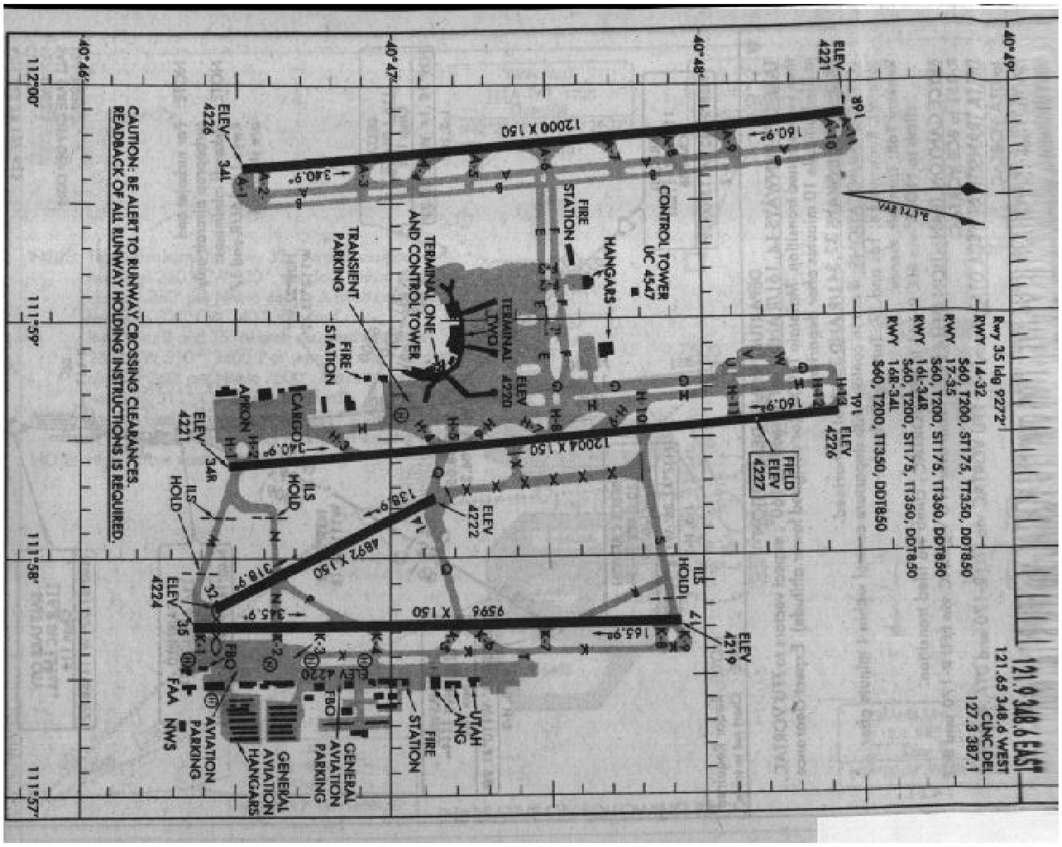
SAN FRANCISCO

SAN JOSE

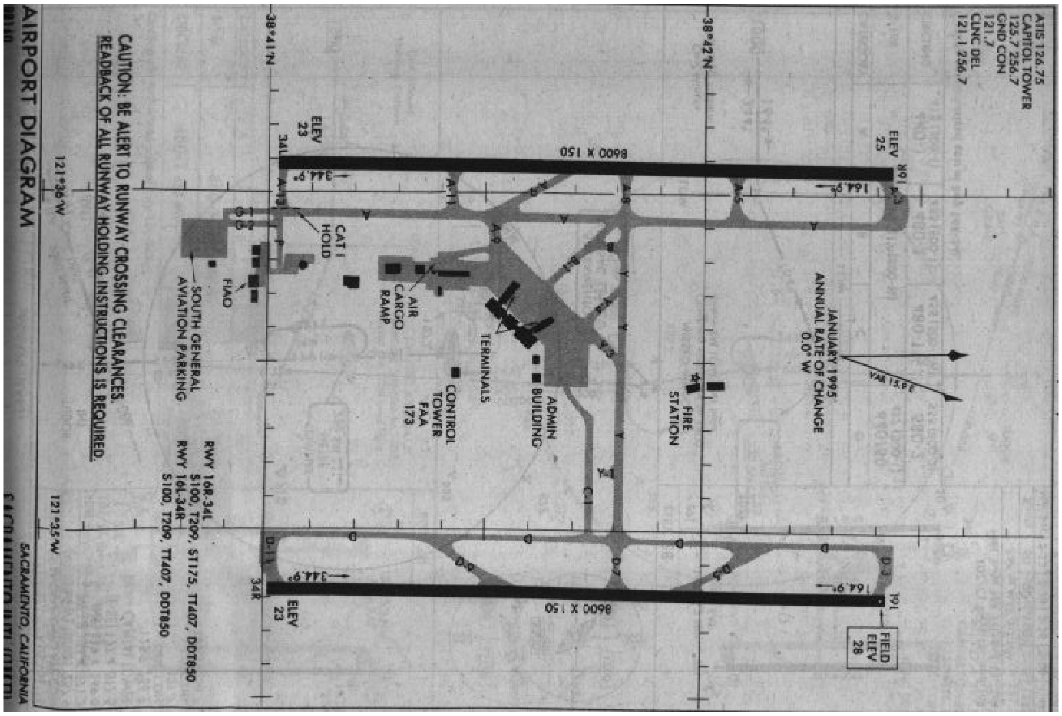


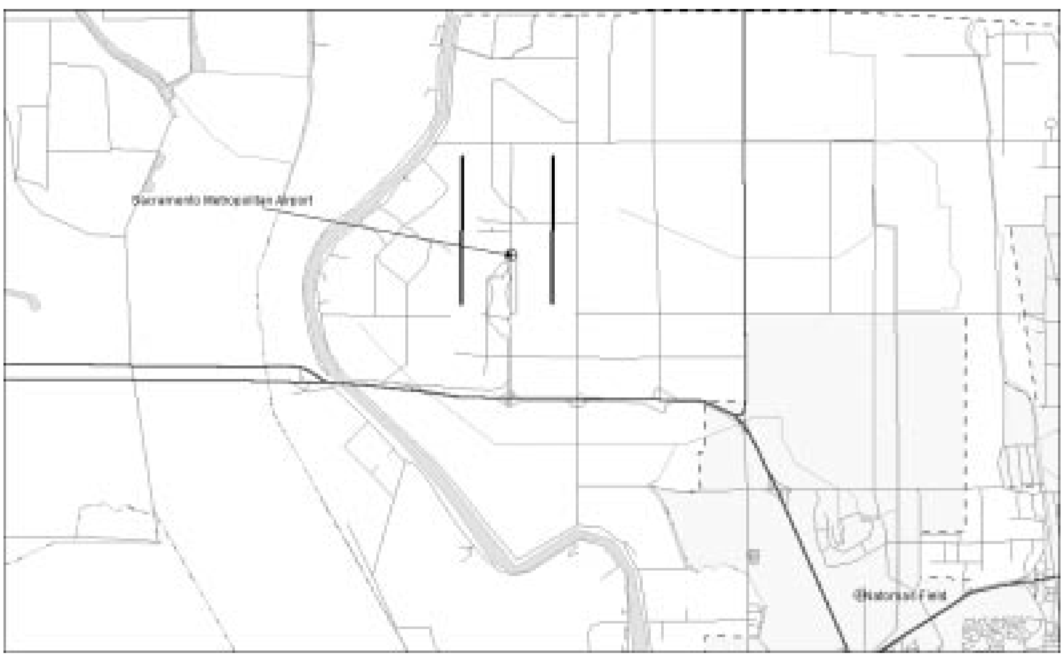


SALT LAKE CITY

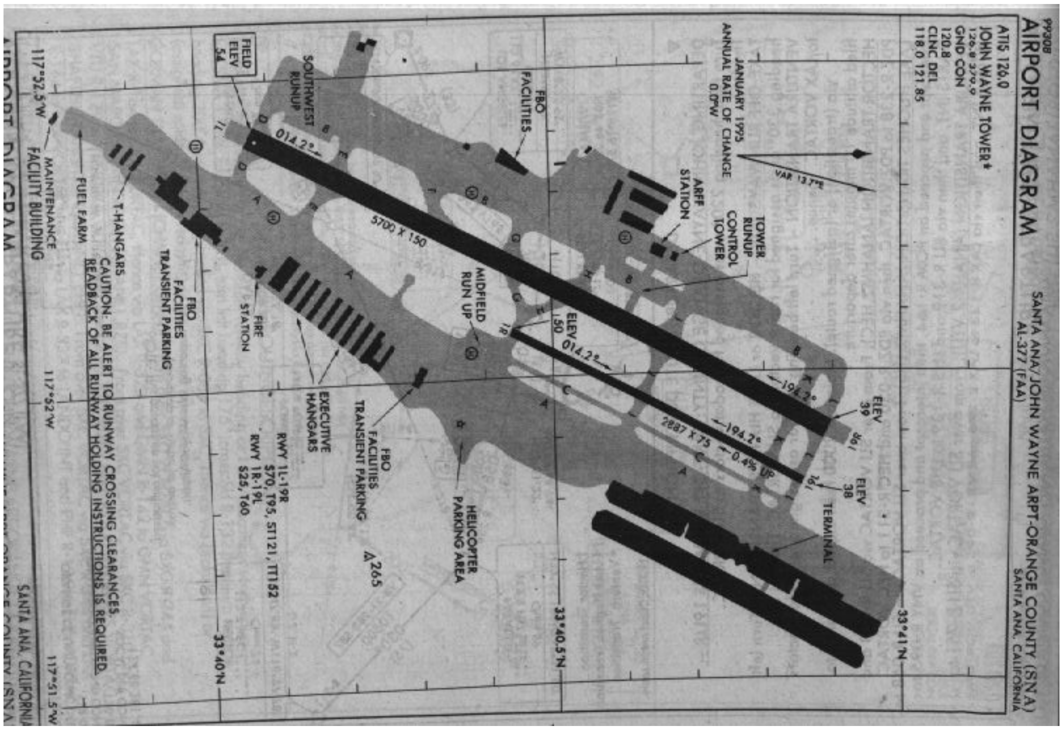


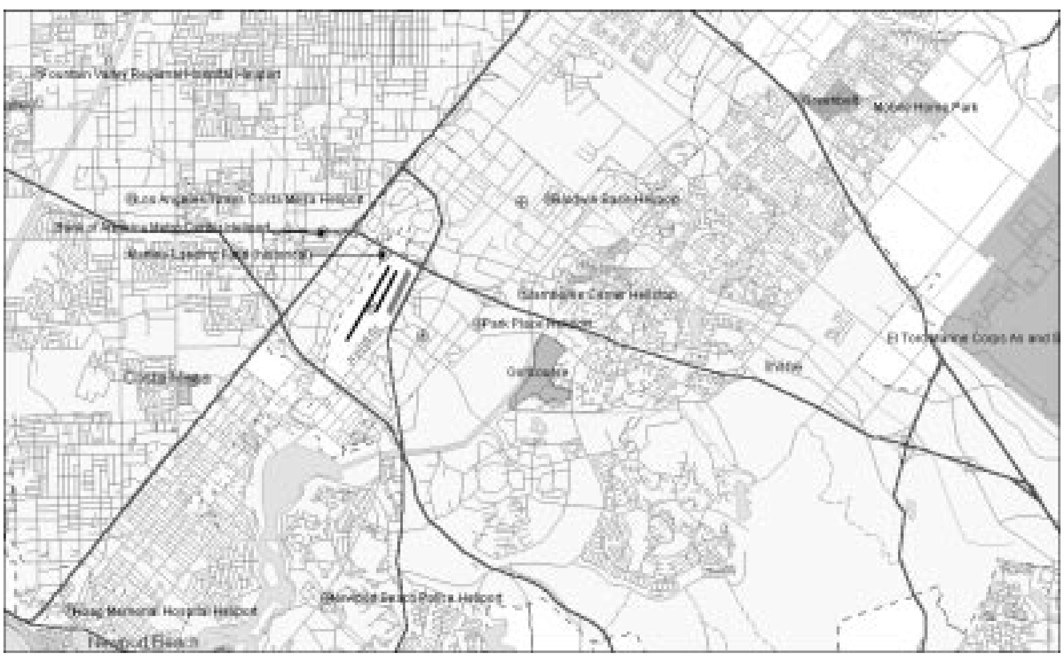
SACRAMENTO


AIRPORT DIAGRAM
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES.
READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
ATIS 126.75
GND CON
CLNC DEL
121.1 256.7
JANUARY 1995
ANNUAL RATE OF CHANGE
0.0° W
8600 X 150
8600 X 150
FIRE STATION
ADMIN BUILDING
CONTROL TOWER
TERMINALS
AIR CARGO RAMP
CAT I HOLD
FIAO
SOUTH GENERAL AVIATION PARKING
FIELD ELEV 28
SACRAMENTO, CALIFORNIA

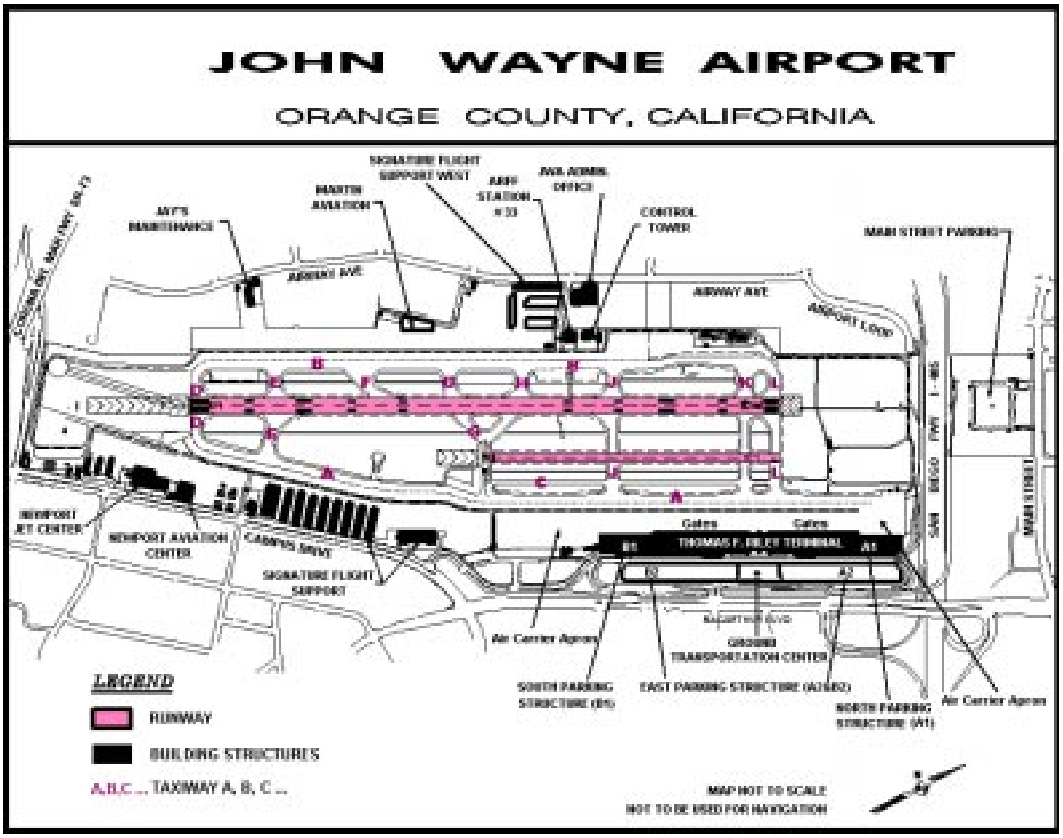

Sacramento Metropolitan Airport

SANTA ANA / JOHN WAYNE ORANGE COUNTY



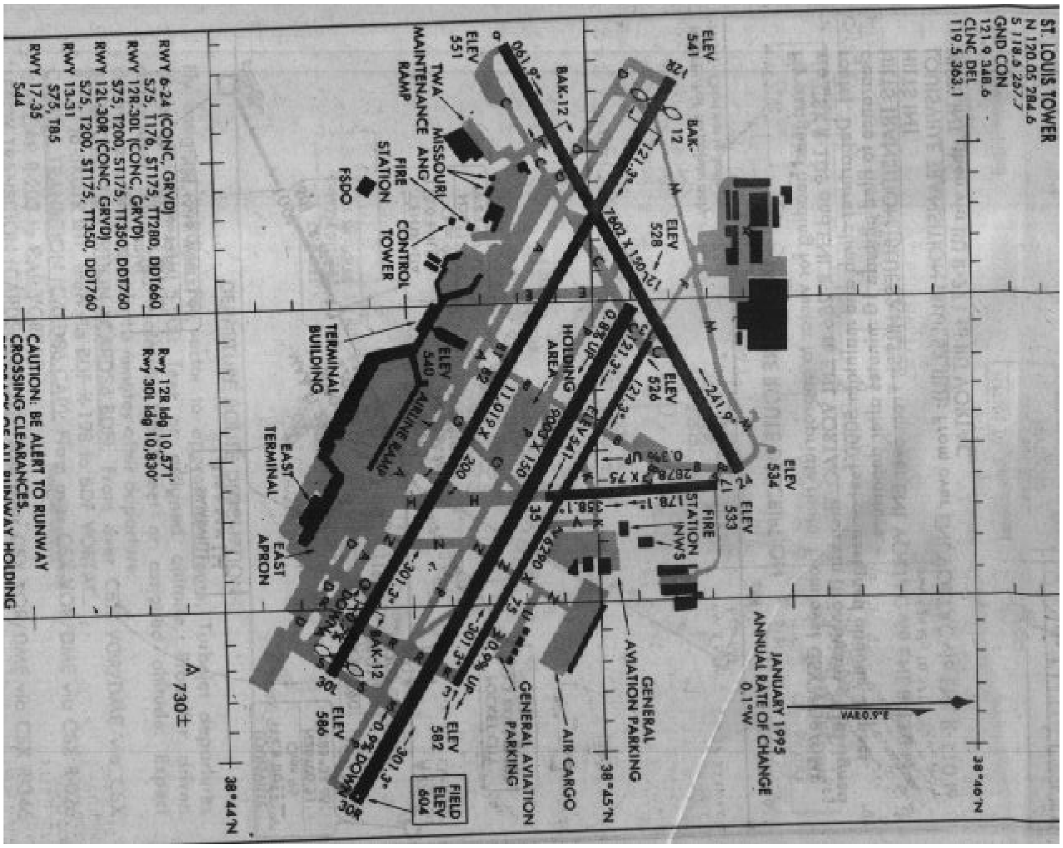


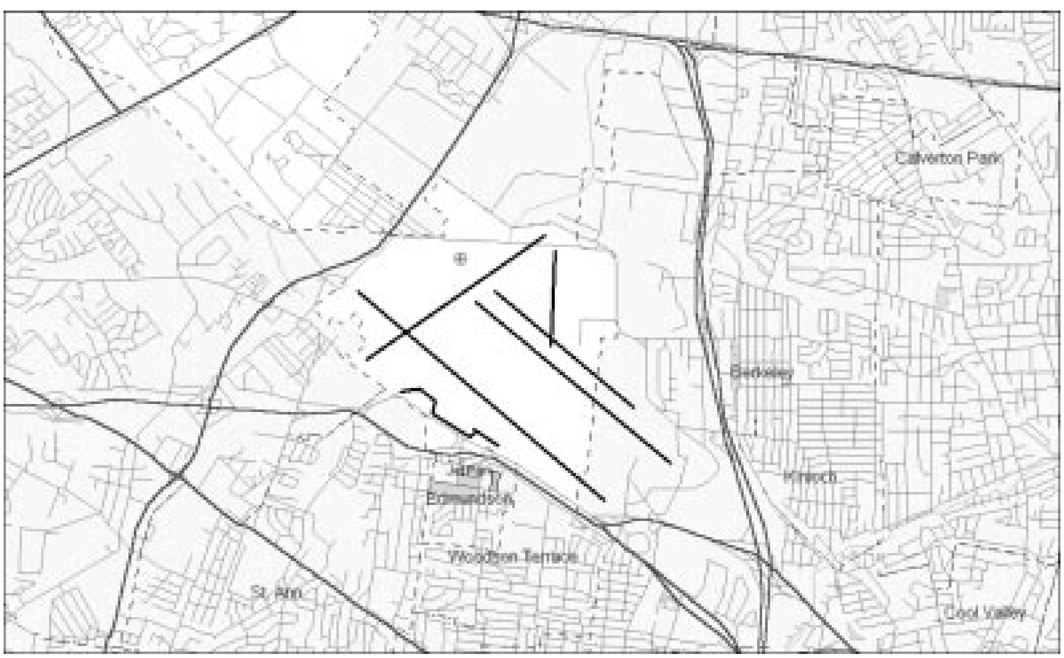
SANTA ANA / JOHN WAYNE - ORANGE COUNTY



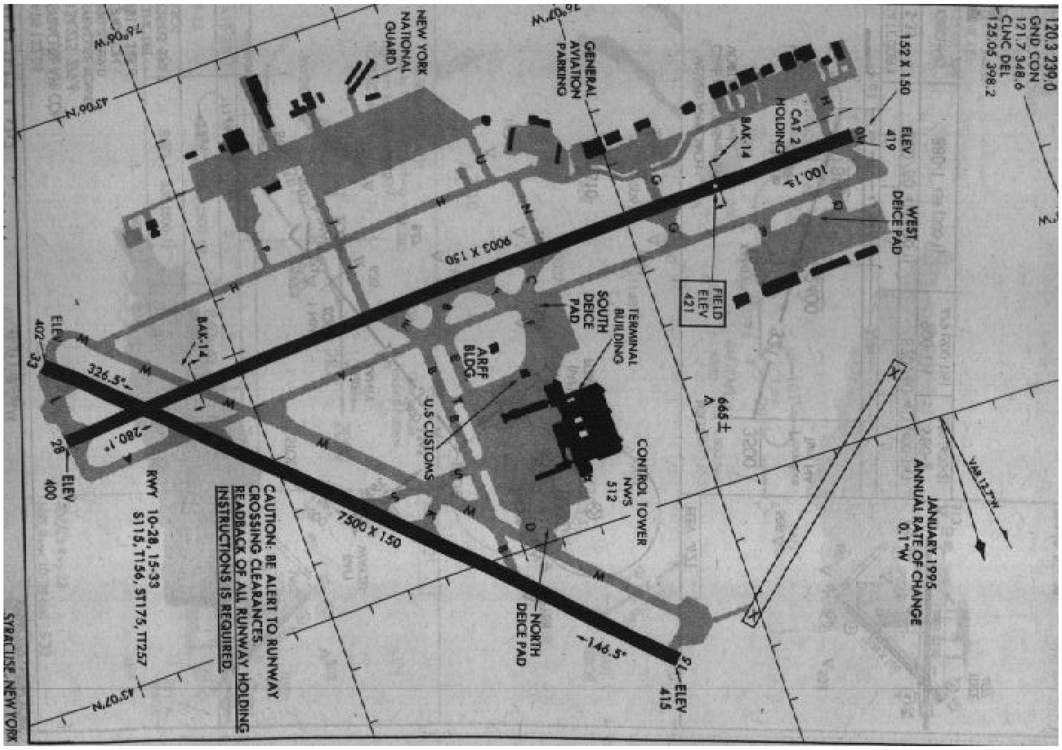
SANTA ANA / JOHN WAYNE - ORANGE COUNTY

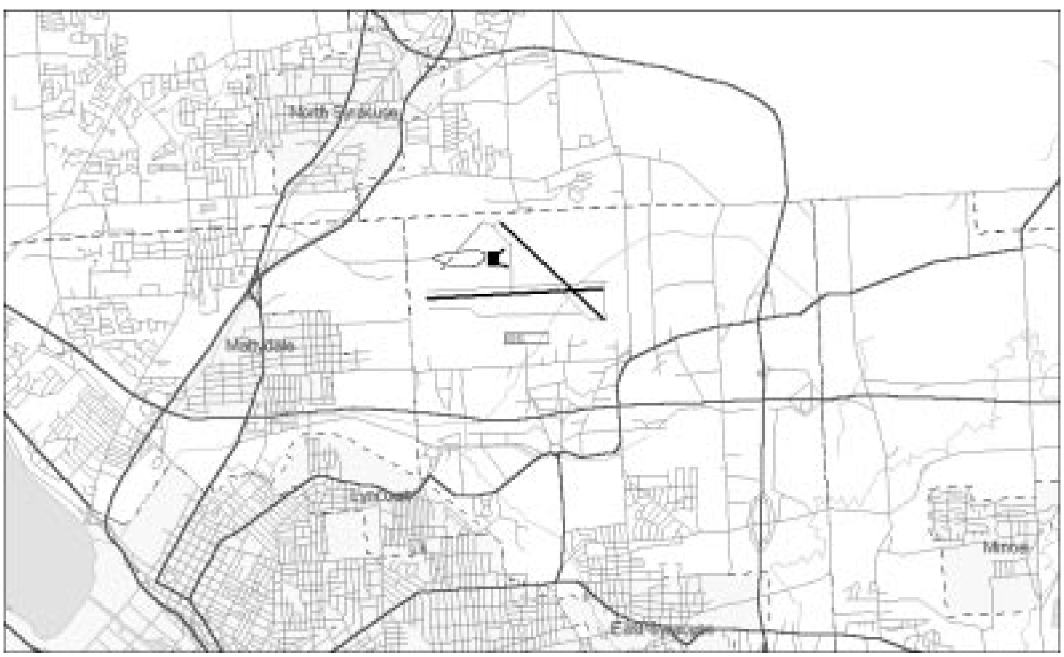
ST LOUIS




Calverton Park
Berkeley
Kinloch
Edmundson
Woodson Terrace
St. Ann
Cool Valley

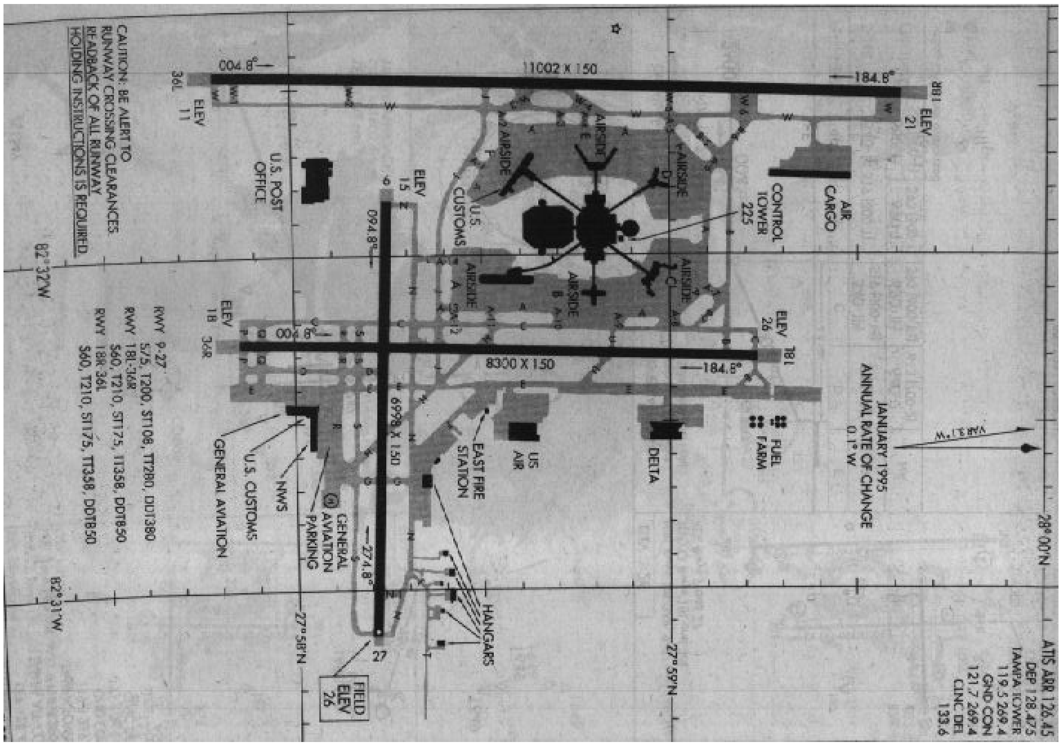
SYRACUSE

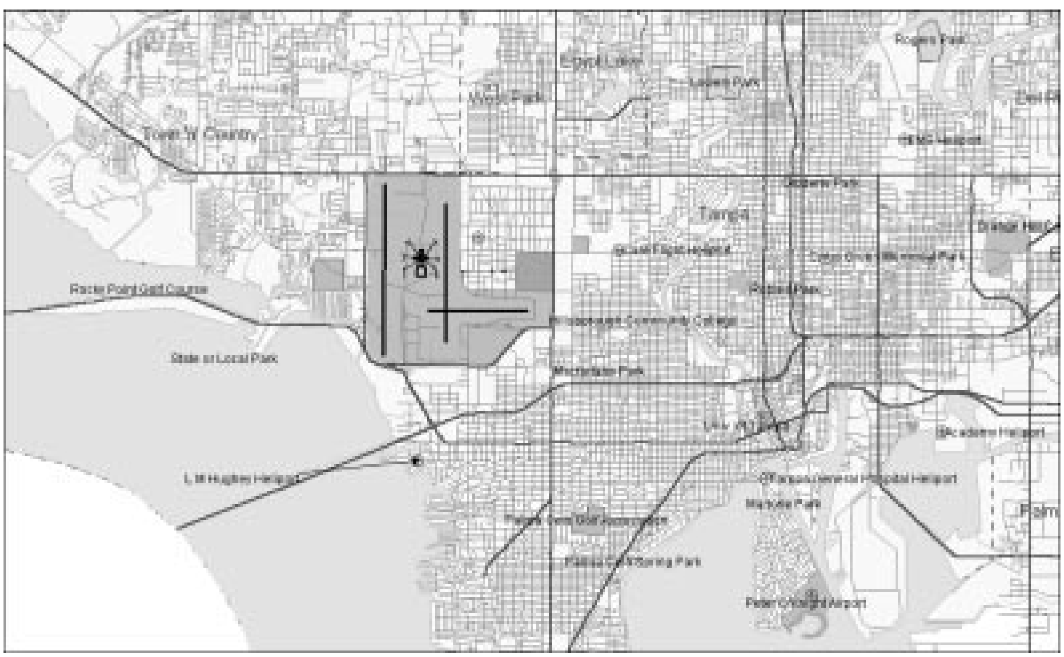

CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES. READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
SYRACUSE, NEW YORK



SYRACUSE

TAMPA


CAUTION: BE ALERT TO
RUNWAY CROSSING CLEARANCES
READBACK OF ALL RUNWAY
HOLDING INSTRUCTIONS IS REQUIRED
11002 X 150
8300 X 150
U.S. POST OFFICE
CONTROL TOWER 225
AIR CARGO
U.S. CUSTOMS
EAST FIRE STATION
US AIR
DELTA
FUEL FARM
JANUARY 1995
ANNUAL RATE OF CHANGE
0.1° W
NWS
GENERAL AVIATION
GENERAL AVIATION PARKING
HANGARS
FIELD ELEV 26
ATIS ARR 126.45
DEP 128.475
TAMPA TOWER
119.5 269.4
GND CON
121.7 269.4
CLNC DEL
133.6


Town 'N' Country
Egypt Lake
West Park
Tampa
Rocky Point Golf Course
State or Local Park

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
September 2001

3. REPORT TYPE AND DATES COVERED
Contractor Report

4. TITLE AND SUBTITLE
Evaluation of the National Throughput Benefits of the Civil Tilt Rotor

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13. ABSTRACT *(Maximum 200 words)*
This study examines the capacity and throughput effects of implementing the Civil Tiltrotor Aircraft on a national scale. The CTR has the unique operating characteristic of being able to take off and land like a rotorcraft (VTOL capability) but cruises like a traditional fixed wing aircraft. It presents the potential for both expanding access to major airports without interfering with fixed-wing aircraft operating on congested runways. The CTR can remove more than 10 percent of the operations at the national level, but between 0 and 100 percent of the operations at any particular airport. Removing these operations drops the average delay down to levels consistent with 2007 unconstrained baseline traffic levels. The key issue is the strategy associated with those “freed” operations slots. Those freed slots represent the price paid for a relatively low average delay time. Reusing those operations will increase enplanements and RPMs, but at a disproportionate increase in average time of delay. The CTR can only be implemented at some airports. Its use at these airports presents the possibility to EITHER reduce delay OR additional NAS capacity. IT CANNOT DO BOTH, as the CTR competes with some of the same key resources as the fixed-wing aircraft.

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